

A GENERATIVE APPROACH TO THE THERMAL DESIGN OF BUILDINGS IN
A HOT DRY CLIMATE (WITH PARTICULAR APPLICATION TO BAGHDAD).

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ABSTRACT OF THESIS

The thesis is concerned with the generation of the thermal form of the building. It starts by defining the thermal form within the total architectural form and analyses it into its parameters. These are found to be the geometry and orientation of the building, the thermal properties of its elements and the geometrical characteristics of its windows and their shading devices.

Dealing with hot dry climate, the thesis takes Baghdad as an example and develops a generative model which can be used in the design process in generating specifications and values for the parameters of the thermal form, with the thermal comfort of the human being as the underlying objective. The model is geared for systematic use by the designer and allows for flexibility in application. It is constructed of nineteen charts and indices and its use is guided by four systematic charts.

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CHAPTER I

INTRODUCTION

A building is a composition of materials and spaces which satisfies a set of human requirements. The task of the designer is to perceive a composition which, if realised, would provide a certain level of satisfaction. Its fulfilment is dependent on the designer's knowledge and understanding of both the constraints and the requirements. Vernacular buildings are probably the most impressive attempts to provide architectural solutions to a set of requirements. Their forms had evolved by a practical process of trial and error. The long period necessary for such an evolution was made possible by the slowness of both the change in the social structure and the technological progress. When the scene is much more dynamic like to-day's this evolutionary process becomes unsuitable.

The contemporary conventional design process can be described as an attempt to simulate the evolutionary process in order to be able to perform it within a much shorter span of time. It is a perceptive process of trial and error ranging between analysis, synthesis and evaluation for the design as a whole as well as for every stage of it from the initial general perception to the final detailed completion. The success of its output is greatly

dependent on the amount of knowledge the designer accumulates from past trials and its relevance to the new problem. Its character is well represented by the analysis-synthesis-evaluation cycle where in the first stage the problem is defined from aspects of constraints and requirements, in the second an architectural solution is found and adjusted, and in the third stage this solution is tested against the constraints and requirements; and thus the loop continues. This can therefore be described as a corrective process which builds basically on adopting and modifying a solution to suit the new problem.

It is possible to describe a well designed building as one perceived through an understanding of the existing conditions, the required conditions and a deduction of the modifications which need to be applied to the first to achieve the second. Subsequently a set of design specifications could be found which describe the suitable architectural solution for the particular problem. This "generative" process is dependent on a good understanding of the architectural media (materials and space), the physical phenomena and the human being. And such an understanding will be most objective when it is based on a familiarity with the first principles which supersedes the kind of knowledge attainable from trial and error processes. At this point in time, this is less conceivable in some aspects than others e.g. the present better

understanding of building materials than of spaces. To present a clearer picture we start by a brief analysis of the architectural form.

The determinants of the architectural form are of two types, human and material. The human determinants are either pertaining to the environment and other physiological functions, or socio-cultural. The material determinants are economical and technological constraints. Each set of these determinants influences the design of a number of building parameters, e.g. external surface colour and shape of shading device, through their design parameters e.g. external surface reflectivity and horizontal and vertical shadow angles. To define the relationship between the architectural form and its determinants we consider a hypothetical synthesis of all design parameters which are influenced by a category of determinants and label it as "component form". By definition synthesis of all component forms results in specifications for a total architectural form. But no one component form can have a practical meaning by itself, since the realisation of any building parameter is influenced by more than one category of determinants. By this analysis a relationship can be found between the "thermal component form", which is the concern of this thesis, and the total architectural form :

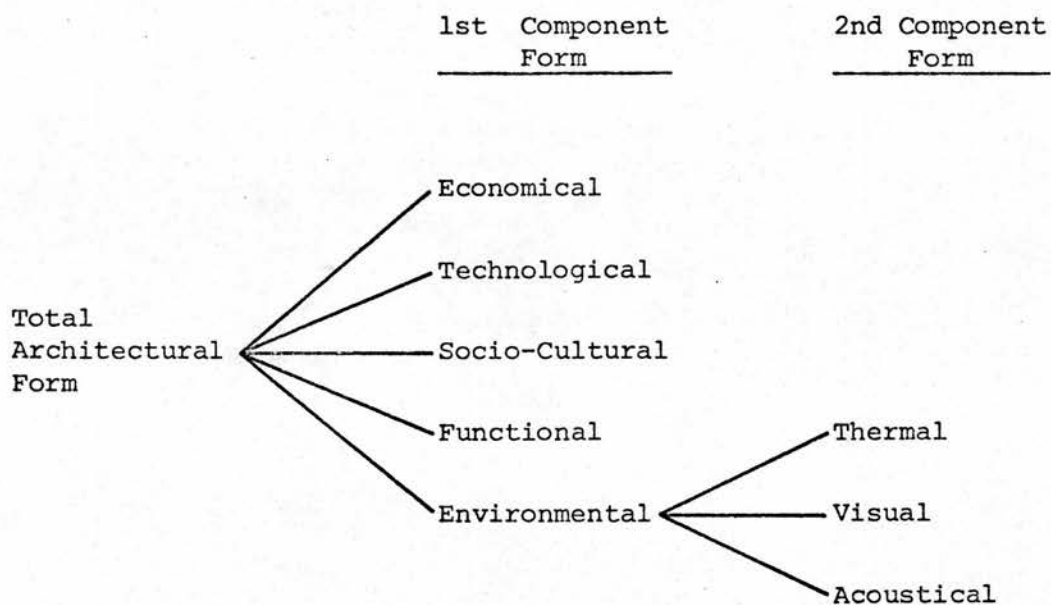


Fig. I.1

In the context of the total form generation this thesis represents one preliminary stage. It arrives at a generative model for parameters of the thermal form(TF).

In the physical world a building (B) acts as a transformation from an empty site (or environment E_0) to the site of the building and the new environment (E_1). This transformation may be expressed (Wilson, 1973) :

$$E_1 = B \cdot (E_0)$$

Under certain circumstances this transformation can also be interpreted to represent the effect of a building in creating an internal environment (E_1) from an external environment (E_0). In terms of the thermal properties and performance of the building we can write :

$$TE_1 = TF \cdot (TE_0)$$

where (TE_1 is the thermal environment required inside the building and TE_0 is the thermal environment outside the building which the thermal form is acting upon to create TE_1 .

In design, the thermal form is an objective. The synthesis of a thermal form starts by a process of two operations, an evaluation of the external thermal environment, and the prediction of values of the parameters of a comfortable internal thermal environment. In the context of the above mentioned equation, thermal design is a solution of the parameter TF which satisfies the relationship. In absolute terms, TF can have an infinite number of values, only a limited number of those would satisfy the above relationship when the range of values of TE_0 and TE_1 are limited.

Separate parameters of the TF influence different channels of the thermal exchange between TE_0 and TE_1 . Form geometry and orientation determine the insolation of opaque elements. The size and

orientation of the window and the design of the shading device determine the penetration of solar radiation to TE_1 . The thermal resistance and thermal capacity and their distribution determine the rate and nature of heat transfer across the external element. The characteristics of openings, which determine the rate of ventilation, indirectly influence the exchange of air borne heat. These interactions between parameters of TE_0 and TE_1 in terms of the heat exchange and the generative process are illustrated by Fig. I.2 and table I.1.

Separate parts of the thermal design process have been studied to great lengths. This was mainly prompted by the fact that these parts were shared by disciplines other than architecture. Evidence for this can be taken from the number of indices developed for thermal comfort and the amount of research done on the properties of climatic elements. Works that have been concerned with aspects or the whole of the thermal form generation process vary in their relevance to the process of architectural design. It, being architectural, demands a certain amount of awareness and comprehensibility of the forces involved, even when they are not directly dealt with. And being a process of design, it relies on accessible conclusions of research. In this light, several works which deal with the problem of thermal design as a whole will be discussed here individually. They can be put into three categories

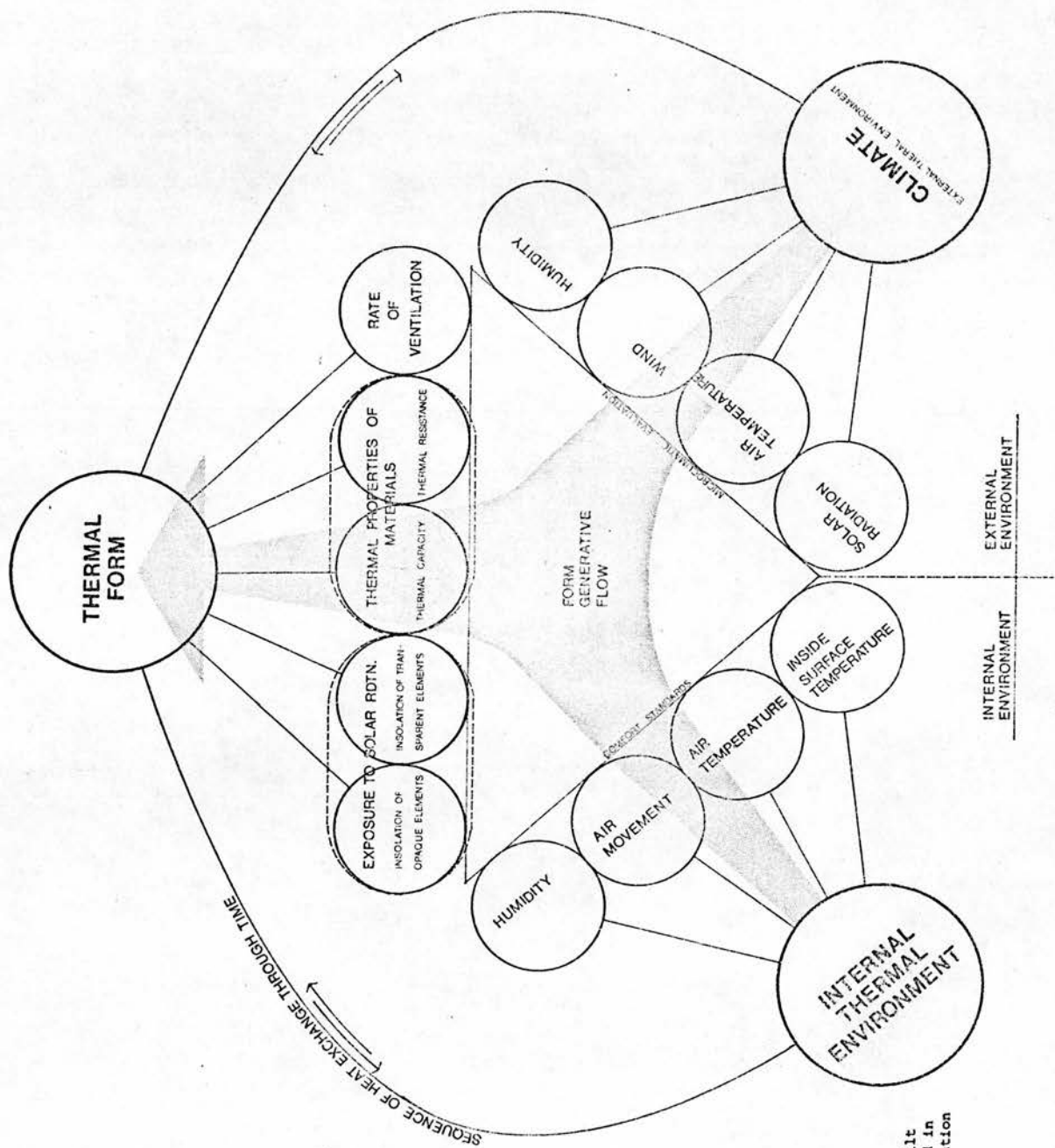


Fig. 1.2
Time in the Built
Environment and in
the Form Generation
Process

TIME →					
1	2	3		5	6
Elements of the External Thermal Environment	Determinants of the Internal Thermal Environment	Elements of the Internal Thermal Environment		Man-Environment Heat Exchange Parameters	Building Design Parameters
		Directly Influenced	Indirectly Influenced		
Solar Radiation -Intensity of Incidence -Duration Air Temperature Long Wave Radiation Air Movement	Thermal Capacity Thermal Resistance	Internal Surface Temperature	Inside Air Temperature	Evaporation	Elemental material content -Choice -Quantity -Composition
Solar Radiation - Intensity - Duration	Insolation of the Opaque External Surfaces Insolation of the Transparent External Surfaces				External Colour Geometry of Building Orientation of Building Relationship to Neighbouring Sun Obstructors Windows -Size -Location Relationship to Neighbouring Sun Obstructors Shading Devices -Vertical Shadow Angles -Horizontal Shadow Angles
Wind Speed Direction	Rate of Ventilation	Air Movement Inside Air Temp	Internal Surface Temperature	L.W. Radiation Convection	Openings -Size -Orientation -Location Locational relationship to one another Relationship to neighbouring wind obstructors Wind Interceptors -Shape -Position
Relative Humidity Wind		Relative Humidity	(The relationships in this row with the building design parameters only exist when rate of ventilation takes a positive value)		Water Bodies -Size -Location Vegetation -Choice -Size -Location

The parameters in column (4) are influenced through the respective ones in column (3) the amount of influence and the time it takes are a function of the efficiency and rate of air circulation in the space.

Table 1.1 The progression of the thermal effect from the External thermal environment to man in the internal thermal environment

Thermal Form

according to their approaches and character of presentation :

- 1- Design with Climate, (Olgyay, 1963)
- 2- Building in the Tropics, (Lippsmeier, 1969)
- 3- Climate and House Design, (U.N., 1971)
- 4- Climatic Design, British High Commission,
Islamabad. (Tropical Advisory Service, 1966)
- 5- Man, Climate and Architecture, (Givoni, 1969)
- 6- Thermal Performance of Buildings, (Van Straaten, 1967)

One of the first books to draw attention to the importance of the awareness of the designer of the thermal problem, at the early stage of the design process, is Victor Olgyay's book "Design with Climate". It aims at a rationality in climatic design by discussing the three spheres involved, climate, thermal comfort of man and building technology. It deals with four kinds of climates, cold, temperate, hot arid and hot humid, and considers planning as well as architectural problems.

The above description demonstrates the size and complexity of the problem the book tackles, which it does by providing evidence and clearly presented information. Yet the only summarised conclusions that can be found in the book are those derived for the particular design problems discussed near the end of the book.

By not providing an easily accessible set of recommendations that can be directly applicable to the design process, the book became of more interest and benefit to the architectural reader, than of direct easy use to the designer.

The book "Building in the Tropics" by Lippsmeier is nearer in character to Olgyay's book than to other works on the subject. Generally, it depends on a display of the problem and a description of the possible solutions. This book, however, deals with the broad problem of building, extending to the implications of the operation itself, and therefore places less emphasis on the problem of climatic design. It also stands short of providing easily obtainable recommendations that can relate directly to the design process and form a guide to the designer.

A common characteristic of the above two works is that they rely heavily on the designer to read the whole book and draw the conclusions, thus demanding a considerable amount of time and attention from him.

On the other hand, the United Nations monograph "Climate and House Design" displays a more successful example of how to deal with a problem of this magnitude. Instead of discussing the research that constitutes the background to the conclusions, emphasis is

on the presentation of the recommendations in a simple, easily accessible manner. It divides the problem of house design into three stages, sketch design, plan development and element design. For the first and third stages, the "Mahoney Tables" provide a systematic procedure which employs climatic data concerning air temperature, humidity, rainfall and wind, to specify recommendations for design. As for the plan development stage, the method adopted is of a different character, it depends on a display of basic information on building types suitable for each climate. Applying data for Baghdad, the recommendations yielded for the sketch design stage are :

- A. Compact courtyard planning
- B. No air movement requirement
- C. Medium opening 20-40% of wall area
- D. Heavy external and internal walls
- E. Heavy roof, over 8 hours time lag
- F. Space for outdoor sleeping required.

As for the element design stage, the recommendations are :

- A. Medium opening 25-40% of wall area
- B. Heavy walls and roofs, over 8 hours time lag
- C. Space for outdoor sleeping required

The above recommendations provide valuable basic information which would particularly safeguard the design from major faults. The main contribution of this work, however, is in its approach. It provides, for the first time, a systematised method by which the designer arrives at design recommendations without being involved in the background study. Moreover, its layout and presentation demonstrate an attempt to understand and fulfil the requirements of the practitioner. In this respect, the monograph achieves considerably more success than other attempts on the subject.

A report on "Climatic Design" in Islamabad, prepared by the Tropical Advisory Service of the Architectural Association, demonstrates another attempt in communicating information to the designer by providing ten sets of recommendations, relating to the various types of decisions in the design process. Being concerned with a fairly defined problem, this report succeeds in providing more specific guidance than others.

The works discussed up to this point are clearly geared to guide and influence the designer directly. "Man, Climate and Architecture" by Givoni, on the other hand, tackles the same general problem but differs in approach and character. It seems to aim at three objectives; the first is a comprehension of the factors involved in the problem and their interaction, the second is a

statement and analysis of relevant scientific work, and the third is an attempt to present the conclusions of research to the designer, thus bridging the gap between research and practice.

This book, being partly written for students, demonstrates considerable success in achieving the first two objectives, and proves to be a good reference to the researcher, but of less obvious use to the designer.

Parallel to this work, but more concerned with the practical aspects of building, is "Thermal Performance of Buildings" by Van Straaten. The author of this book defines its main purpose as one of outlining design principles "in terms that are understood by architects, engineers, building inspectors and building scientists". Although the book deals with the various aspects of the subject in separate chapters, which it claims to be independent and complete in themselves, it can be taken as a proof to the complex overlapping of these aspects. A clear sign for this is the reference in the individual chapters to other parts of the book which is not infrequent.

In general, the last two books are similar, apart from the fact that the first book goes to a greater length and shows more success in attempting to communicate research findings to architectural designers. Yet both have considerable drawbacks in this respect.

From the above review, it is possible to outline the main disadvantages that are common between works concerned with this field, define the gaps that need to be bridged and, in light of this, suggest an approach.

A major fault of some of these works is the amount of time and effort they demand from the designer. Being concerned with all aspects of the architectural form, the designer is likely to find it difficult to spare the time necessary for reading throughout a book concerned with background research and discussion of the subject. Moreover, these works seem to depend to a large extent on the designer's interest in the scientific aspect of the subject. This, in view of the size of the task of architectural design, can be considered ^junjustifiable and distracting for the designer from the more important part of his job, namely the synthesis of the form. /j

These faults, however, are not shared by the monograph "Climate and House Design", which provides a systematic approach. Dealing with the wide problem of hot climates, however, the monograph could only provide general guiding lines of wide applicability. This is of greater value to the foreign practitioner than to his local counterpart. It is considered in this thesis a priority to provide specific and readily processed information for thermal

design in a particular locality rather than general recommendations geared for universal application.

1. Objectives and Outline of Thesis

1.1 Guidelines for the Envisaged Approach

The need therefore arises for an approach based upon the following :

- A. Rational and scientific thinking aiming ultimately at the thermal comfort of man.
- B. A logic based on systematic thinking and expressed diagrammatically providing for easy access and a clear method of use.
- C. Comprehensibility of all the parameters of the thermal form and their fit within the total architectural form.
- D. An understanding of the architectural design process within which any recommended method will have to fit.
- E. An awareness of the magnitude of the effect of the factors that are not directly dealt with, allowing for their influence in design.

- F. Flexibility and provision for alternative satisfactory solutions wherever possible.
- G. The provision of guidance with the least possible non-thermal restrictions.
- H. The concern for a generative method which does not unnecessarily involve the designer in the background study.
- I. The provision of specific yet clear guidance that would be of value to the designer in all stages of the design process.
- J. A direct relevance to design parameters in their practical terms instead of the scientific terminology where possible.

Using these points as guidelines, this thesis aims at developing a generative model. It relies on established knowledge where possible and develops suitable criteria where necessary, endeavouring to bridge existing gaps in the field and seeking a rational generative approach to all parameters of the thermal form.

1.2 Layout of the Thesis

The thesis is divided into six chapters. The first is introductory, the last displays the complete generative model and discusses its use, and the four intermediate chapters describe the development and construction of the model. The basis of the structuring of the intermediate part, which follows this discussion, is one of separation between the parameters of the architectural form which determine the internal thermal environment. They are categorized as follows :

- A. Form geometry and orientation
- B. Design of the element
- C. Further control of the internal thermal environment

The first category is concerned with the relationship between the building and the sun and uses the fact that the geometrical form and orientation of the building determine its insolation. It is dealt with in Chapter II where a criterion is developed for generating suitable geometrical forms and evaluating them and their orientations.

The second category involves the design of the element. In

the case of walls and roofs, this does not include their orientation and inclination, since these are a function of the last category. Chapter III, which deals with this category, divides the elements into two kinds, opaque and transparent. For the opaque element, it covers the external colour, material content and composition. The transparent element, on the other hand, is described by two things, insulation and design. These respectively involve the geometrical properties of the shading device, and the size, orientation and construction of the glazed element.

The third category is dealt with in Chapter IV. It is concerned with the prediction of the internal thermal environment of a building of a good thermal design. It evaluates the possible deviations of the descriptors of this environment from their comfort values. In this light complementary thermal control is suggested.

Chapter V is almost solely devoted to the description of a computer model developed to provide a means for generating geometrical forms and based on the evaluation of the unit area of the individual element. The model deals with five types of geometrical forms and is devised to find the optimal combinations of form type, proportions and orientation. It is used in this thesis: in evaluating forms from two viewpoints, their

insolation and the amount of materials necessary for their assembly. The last part of this chapter is concerned with the relationship between proportions, volume and dimensions of the geometrical form of the building.

The final and sixth chapter of the thesis contains the whole generative model constructed of charts and indices, which have been developed throughout the thesis, in addition to systematic flow charts which explain the method of use of the model in design. The chapter also includes a discussion of the model and its implications and a demonstration of its use in a design problem.

The six chapters of the thesis are supported by eight appendices positioned at the end of the book. The function of the individual appendices vary between some mathematical ones, which are complementary to particular arguments in the chapters, and others which can be viewed as sources of information, and which are referred to frequently throughout the thesis.

The aim underlying the organisation of the thesis is to display as clearly as possible the development, construction and use of the generative model.

CHAPTER II

FORM GEOMETRY AND ORIENTATION

1. General

The intuitive approach to decision-making by the designer, on the geometrical properties and orientation of the building from a thermal viewpoint, is presumably induced by the acceptance of some established general criteria concerning the design characteristics governing the building's thermal behaviour, e.g. insolation. This is usually coupled with knowledge of the basics of the geometry of the solar trajectories.

Lippsmeier (1969) devotes a relatively short paragraph to the relationship between the insolation of the building and its orientation. He briefly discusses that a rectangular building in the tropics is better situated when its long facades face the north and south. The Mahoney tables (U.N., 1971) lead to recommendations for either an east-west axis for orientation or compact courtyard planning.

The Tropical Advisory Service (1966) considers the total solar radiation received by vertical surfaces during the hot part of the year against that of the cold part. An assessment of the orientation possibilities is done for single facade, terraced and detached houses, and in conclusion, exposure to S.30°E (30° east of south) is found

to be favourable for Islamabad.

A similar approach is used by Olgyay (1963) in evaluating plan ratios for different climates. He suggests an optimum ratio of 1:1.3 for a hot-dry climate with the orientation of the long side towards S.25⁰.E.

In an approach towards understanding the problem of orientation, Givoni (1969) discusses the effect of orientation on the internal thermal environment, by studying its interaction with the colour of the external surface and the thermal properties of the wall. It can be concluded from his experimental studies that, to a certain extent, it is possible to treat internal temperature conditions independently from orientation by suitable use of some building parameters, like external colour and material content of the building elements. These cases generally demonstrate the prevalent attitudes of research on the subject of geometry and orientation. It is of interest at this point to focus on the following common features in these approaches:

- A. There appears to be more emphasis on working towards a favourable orientation, which stems from the evaluation of the insolation of the individual vertical elements, instead of considering three dimensional forms, where the insolation of the roof can be taken into account.

- B. A failure to consider the insolation of inclined planes and forms which include inclined elements.
- C. Recommendations for orientations are almost always dealt with by suggesting one optimum orientation, which is a considerably rigid approach. The trend here should be to provide for flexibility by dealing with favourable geometries or plan proportions for possible orientations or the opposite.
- D. The relation of the recommendations to the design process and awareness of the non-thermal forces involved are generally inadequately expressed. Evidence for this can be taken in the lack of provision for alternative solutions that are, although short of the optimum, of satisfactory value.

More objectively, if these values are presented to the designer, they would provide him with a clearer picture of the advantages or concessions accompanying the adoption of any particular solution.

- E. There is an absence of means which would enable the designer to thermally evaluate orientations or geometrical forms that are possibly dictated by non-thermal forces, without having to be involved with the background research and computations.

The above points are main common features in the field which, if overcome, will help in making a more effective use of research findings in influencing architectural design. The generation of the form geometry and orientation, however, starts by a study of their determinants e.g. thermal comfort, external thermal environment.

1.1 Characteristics of Forces Influencing the Generation

The character of the problem looked at here requires a consideration of the mechanism of the thermal interaction between the external and internal environments, as well as the properties of the climatic elements and the thermal comfort of the human being.

It would not be unjustified to assume that exposing a man to solar radiation, when air temperature is near the upper border of the comfort range, would introduce thermal stress. But this is a much more straightforward case than that of a man sheltered by a building made of heavy materials.

The time lag produced by the high thermal capacity of a material, multiplies the intricacy introduced by the considerable daily fluctuation of the thermal conditions in a hot-dry climate, making the predictability of the relationship between

the external and internal environments that of great complexity.

The complexity of the example of Baghdad can clearly be seen in the study of its climate in Appendix VIII. It can be described as that of two major scales of variation, daily and seasonal. The amplitude of the daily fluctuation of the temperature varies between 11.7°C in January to 18.8°C in September. Since the difference between the two limits of the comfort zone is 8°C (see Appendix IV), at no time in the year does the air temperature fall in full within the comfort range. Sunshine, on the other hand, varies between a mean January day duration of 6.2 hours totalling 11070 kJ.m^{-2} radiation on the horizontal, to 11.5 hours in a June day totalling 30238 kJ.m^{-2} .

This adversity in the climate clearly calls for a line of thought which is sensitive to its diversified character. Thus a consideration of the cold period as well as the hot period with appropriate regard for each of the cases is essential.

1.2 Choice of the Generative Climatic Data

The climatic data employed for the purpose of architectural design, has usually been that which is chosen for engineering

purposes. This is proved by the fact that the two sources providing some of the most used design data are the American Society for Heating and Refrigerating Engineers (ASHRAE, 1967), and the Institute of Heating and Ventilating Engineers (IHVE, 1970).

Van Straaten (1967), presents an extensive study of the problem in what can be viewed as a more architecturally orientated approach. He presents a concept of a design day for South African purposes. It involves the averaging of hourly data of the twenty hottest and twenty coldest days in each of five years. The outcome is a set of climatic data for one hot and one cold day. The terms hottest and coldest mentioned above refer to days with highest or lowest recording of dry bulb air temperature in the year.

This method seems to be mainly aimed at finding representative climatic data, but places much less emphasis on the important aspect of choosing information which is directly relevant to architectural design.

In the case of design, what seems to be the problem is the link between the available data and the generative process. It is for this reason that it was taken as a policy in this work to discuss the choice of the relevant climatic data whenever the

need for them arises.

Taking air temperature as the basis in making the differentiation between the cold and the hot periods in Fig. II.1, there are three alternative methods of classification. The first one is by use of a vertical division, which implies a seasonal categorization, the second uses a horizontal division marking a temperature level, and the third uses both, horizontal and vertical divisions.

A seasonal categorization means the drawing of a vertical line on the graph separating two consecutive periods and labelling them according to the side of the line they fall on; thus one cold and one hot. This procedure, although relatively easy for application, can be considered crude in the sense that it treats the whole day as of uniform thermal character which can hardly be the case in a hot-dry climate.

The application of two dividers, horizontal and vertical means an evaluation of the daily thermal behaviour over a period of time less than a year. Assuming that one of the objectives of a building's design is to provide the closest possible internal thermal environment to that required for comfort during as large a part of the year as possible, any design period of less than a year would have to be represen-

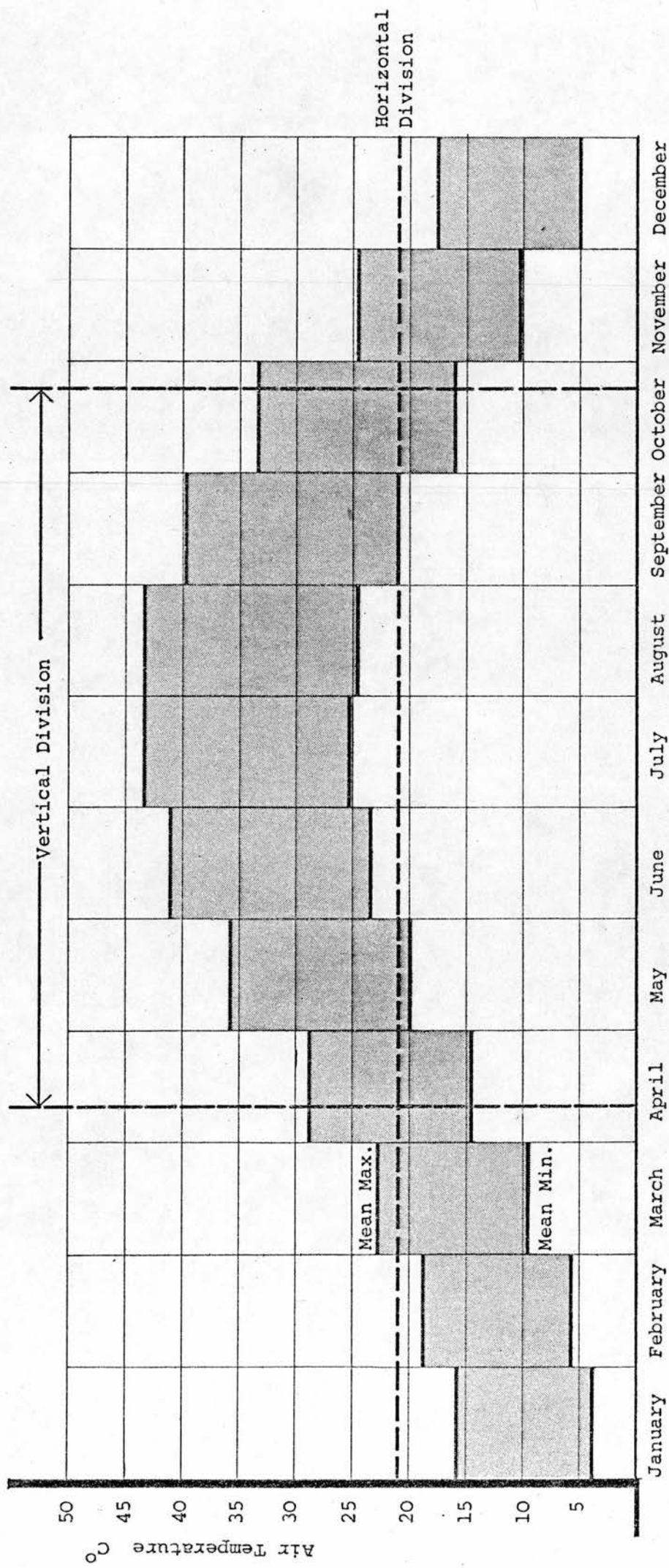


FIG. 11.1 A Comparison of the methods of categorization of the thermal conditions in Baghdad - App.VIII

tative of either the whole year or the thermally dominant parts of it.

A horizontal division on the other hand makes the differentiation possible between the cold and the hot parts of each day in the year, and thus evaluates their thermal characteristics accordingly. The important decision here is that of the temperature level at which the horizontal line is drawn. This decision must be made in light of the purpose for which the procedure is being carried out.

In all cases, the ultimate consideration seems to be that of one complete design year representative of the climate; i.e. data would have to be averaged over a period of a minimum of, perhaps, 20 years. This kind of information is sparse for solar radiation intensity, for which values will have to be computed, but it is available for the other climatic elements.

2. The Over-21 Concept

2.1 Logic of the Concept

As has been concluded above, an evaluation of the complete cycle of thermal conditions in the hot-dry climate can best be made by a horizontal division marking a thermal condition

separating some days into two parts, and categorizing the others as completely over or under the mark. An important decision which will have to be made here is the critical thermal condition at which the mark is to be made.

The difficulty of the predictability of the relationship between the external and internal thermal environments, which has been previously discussed, makes the choice of the thermal level one of appreciable difficulty, since the thermal conditions on either side of the level will be treated differently, and since the effect of the thermal capacity is to delay the effect of the earlier side, to the time of occurrence of the other. Any choice on this matter will therefore have to be made accordingly and shown to be valid.

As has been discussed in the introduction, the building controls the extent of the influence of the external thermal environment on the internal thermal environment. Each of the building design parameters has a controlling effect on the influence of one or more of the climatic elements. The colour of the external surface determines the amount of influence of the solar radiation, yet not that of the air temperature, humidity or wind. The geometrical properties of the form, on the other hand, affect the influence of the solar radiation and air temperature. The relationship between form

geometry and air temperature is of a simple character. The influence of air temperature can be taken as inversely proportional to the value of the compactness of the form which is represented by the ratio of the volume to surface area. [?] SIV But the case for solar radiation is a more complicated one. Its influence is dependent upon the value of the exposure of the form to it, which is a joint function of the geometries of the solar trajectories and the form.

Considering time, these implications have different consequences in design, since the hourly exposure of the form is constant towards air temperature and variable towards solar radiation. The form geometry, therefore, can only be related to the variation in the solar radiation, but not to that of the air temperature. It is possible to say at this point, that form geometry could be made to act discriminately towards solar radiation received at different times of the day.

On the other hand, thermal comfort of man, which is the criterion behind thermal design, can be more practically presented by values of air temperature. Moreover, the daily variation in air temperature, which follows in part that of the solar radiation intensity, can be taken as indicative of the behaviour of both elements. This leads us to conclude that for the control of insolation, a critical air temperature level

----- Daily Cycle
 --- Annual Cycle

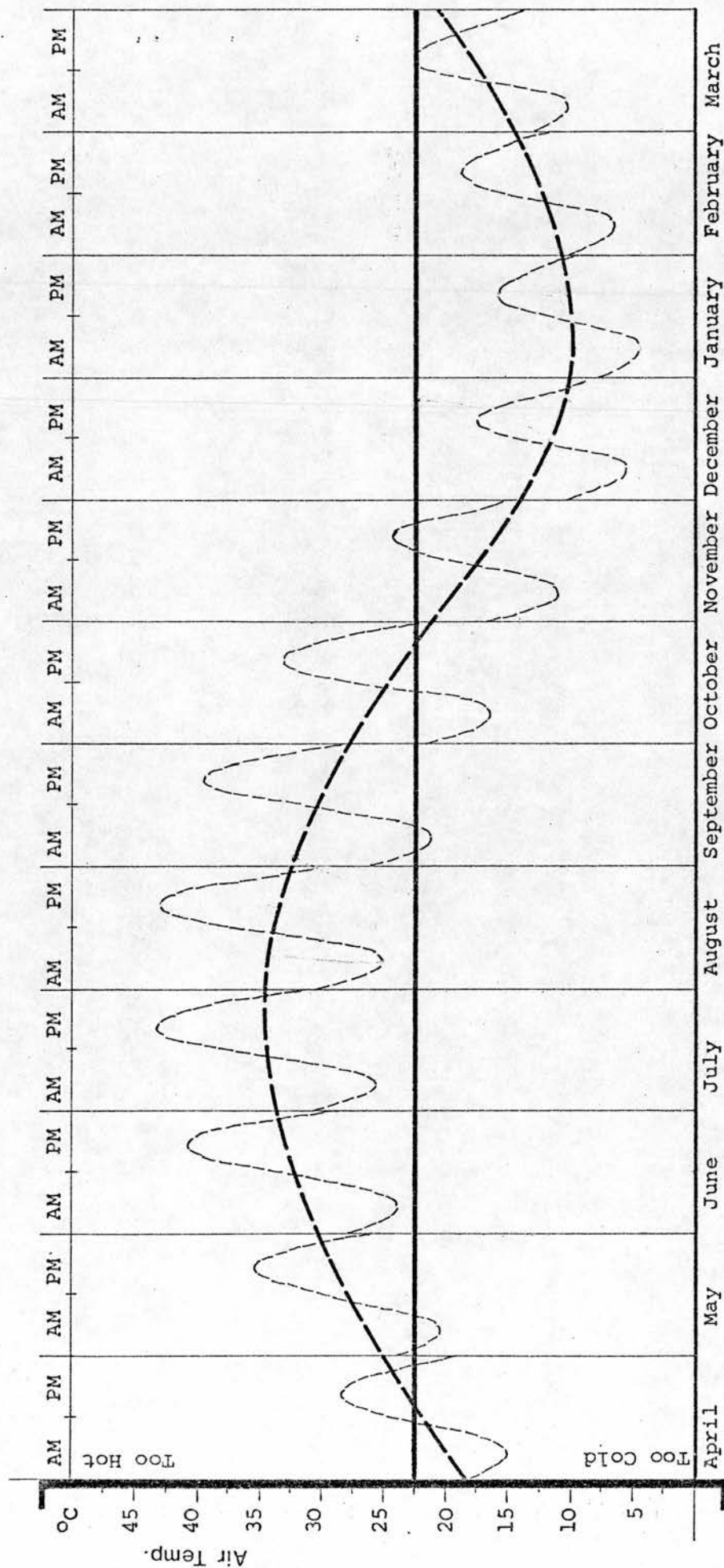


FIG.11.2 The dual scale function of the thermal form of the building in hot-dry climate
 The daily and annual temp. fluctuations are represented by hourly values of
 twelve monthly average days for Baghdad

can be considered.

It will be discussed later in the thesis, that the lowest temperature at which a man in the shade would feel comfortable, and at which insolation would either produce warmer comfort or overheating is 21°C . The time of occurrence of this value is taken to represent a barrier before which insolation is considered as desirable, and after which as undesirable. The value is also chosen on the assumption that with considerable time lag of the materials, the radiative heat received in the under-21 period, which arrives during the early part of the day, will not elevate the thermal conditions of the later over-21 period. A typical example to this can be taken in a vertical white wall facing S. 60°E . As can be found in the systematic process described later in the thesis (see Systematic B of the model in page VI.14), the necessary material content of such an element is constituted of 11cm concrete plus a layer of 2.5cm of polystyrene placed on the external side and protected by a sheet material. This construction of a wall was calculated to yield a time lag of 10-14 hours (U.N., 1971), thus approximately half the fundamental wavelength of twenty four hours. This could be taken to mean that any solar heat absorbed by the wall at the hour of 8 a.m. in a June day will not affect the temperature of the internal surface before 8 p.m. i.e. after sunset, when the external thermal conditions have

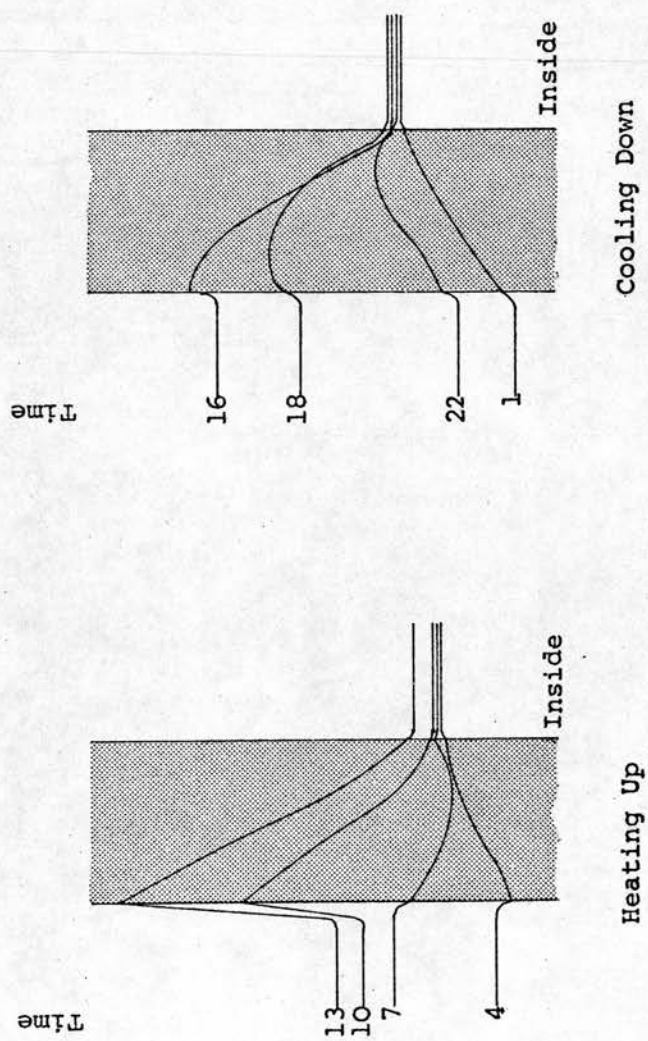


FIG. 11.3
 The effect of the fluctuation of the external thermal conditions on the heat flow through a high thermal capacity wall expressed by temperature gradients across the wall. (LPSMEIR 1969)

considerably depreciated and the direction of the heat flow at the external surface has changed, as can be seen in Fig.

II.3.

This approach may not be specific enough for high academic accuracy, but it is an objective of the thesis to provide a means which, until a more exact approach could be found, can be of direct use to the designer. It is in light of the size and great complexity of the problem that some assumptions have to be made and exactitude have to be waived adopting pragmatism in favour of bridging the gap between research and practice.

2.2 The Over-21 Insolation of Inclined Elements

2.2.1 Insolation of an Inclined Elemental Plane

A. Direct Radiation

In Fig. II.4 inclination of plane (β), plane-solar azimuth (A), solar altitude (α) and the angle between solar rays and normal to plane (n) are related by (ASHRAE, 1967):

$$i) \cos n = \cos \beta \sin \alpha + \sin \beta \cos \alpha \cos A$$

The relationship between the intensities of direct normal radiation (I_N) and direct incident radiation (I) is :

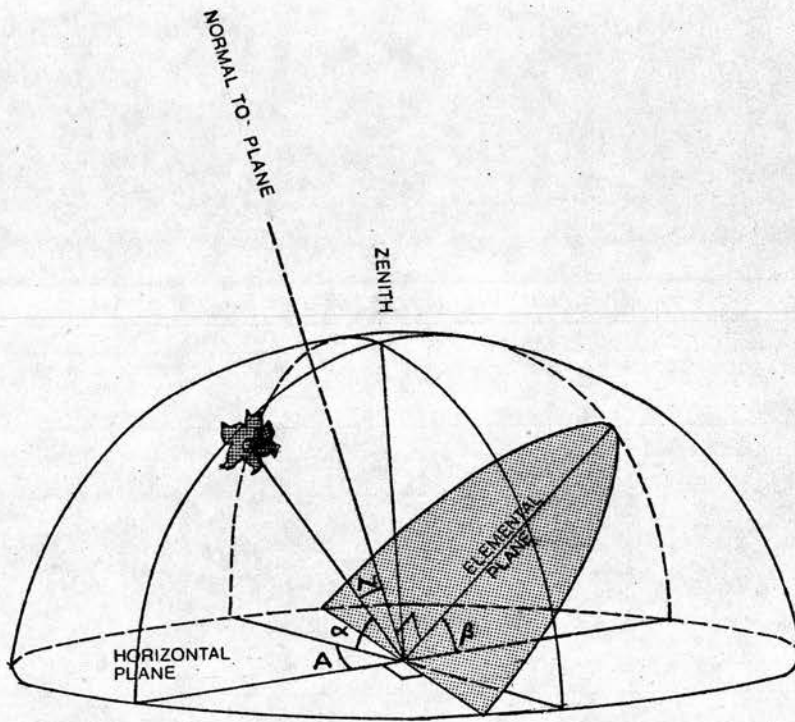


Fig. 11.4

The Geometric Relationship Between the Elemental Plane and the Sun

$$- \text{ii)} \quad I = I_N \cdot \cos n$$

Substituting for $\cos n$ from i) in ii) :

$$\text{iii)} \quad I = I_N (\cos \beta \sin \alpha + \sin \beta \cos \alpha \cos A)$$

Using this equation and the three equations in Appendix I the following relationship can be found (Robinson, 1966) :

$$\begin{aligned} \text{iv)} \quad I = I_N & (\cos \beta (\sin \varphi \sin \delta + \cos \varphi \cos \delta \cos H) \\ & + \sin \beta (\cos A_p (\tan \varphi (\sin \varphi \sin \delta + \cos \varphi \\ & \cos \delta \cos H) \\ & - \sin \delta \sec \varphi) + \sin A_p \cos \delta \sin H)) \end{aligned}$$

where (φ) is the geographical latitude, (δ) is the solar declination, (H) is the hour angle and (A_p) is the plane azimuth measured from south.

The intensity of direct normal solar radiation is given in Appendix III by :

$$\text{v)} \quad I_N = M \cdot \text{EXP} (-N / (\sin \varphi \sin \delta + \cos \varphi \cos \delta \cos H))$$

where (M) is the solar constant and (N) is the extinction coefficient. Values for (M) and (N) are given in Appendix III, Table A III.1 for the 21st of each month.

Equations iv) and v) can be used in calculating the intensity of direct solar radiation incident on a plane of inclination (β) at a time (H) .

B. Diffused Radiation

Investigations carried out in India (Sharma and Pal, 1965) show that 12% of the total radiation received on clear days is in the form of diffuse radiation. This percentage increases with haziness up to a maximum value of 35%.

For clear skies, the diffuse radiation falling on a plane (I_{DF}) can be calculated by using the equation : (ASHRAE, 1967)

$$\text{vi) } I_{DF} = K \cdot I_N \cdot \beta_s$$

Where (K) is a dimensionless factor given in Appendix III Table A.III.1 and (β_s) is a factor determining the exposure of the plane to the sky where the sum of all the angle factors between a plane and its surroundings is a unity.

The plane-ground factor (β_G) is therefore :

$$\beta_G = 1 - \beta_s \quad \text{when considering the plane, the sky and the earth}$$

But (β_G) and the inclination of the plane (β) are related (ASHRAE, 1967) :

$$\text{vii) } \beta_G = \frac{1}{2}(1 - \cos \beta)$$

$$\text{therefore } \beta_s = \frac{1}{2}(1 + \cos \beta)$$

By eliminating (β_s) from vi) and viii) we can write :

$$\text{ix) } I_{DF} = \frac{1}{2} K I_N (1 + \cos \beta)$$

C. Reflected Radiation

The radiation reflected by the ground to a plane (I_{RF}) can be computed as a function of intensity of global radiation falling on the ground (I_{GG}) and ground reflectivity (r) (ASHRAE, 1967):

$$\text{x) } I_{RF} = I_{GG} \cdot \beta_G \cdot r$$

(I_{GG}) can be computed by summing up the diffuse and direct radiation. Thus, from equation vi) and Fig.

II.4 :

$$I_{GG} = I_N K \beta_s + I_N \sin \alpha$$

Since for the ground, $\beta_s = 1$, we can write

$$I_{GG} = I_N (K + \sin \alpha)$$

Substituting for (I_{GG}) in equation x) :

$$I_{RF} = I_N \cdot r \cdot \beta_G \cdot (K + \sin \alpha)$$

Substituting for (β_G) from equation vii)

$$\text{xi) } I_{RF} = I_N r_{\frac{1}{2}} (1 - \cos \beta) (K + \sin \alpha)$$

Table A V.1 in Appendix V gives a set of values of
(r) for ground surfaces common in hot-dry climate areas

The global solar radiation falling on a plane (I_{Global}) is the
sum of equations iv), ix), and xi) :

$$I_{\text{Global}} = I + I_{DF} + I_{RF}$$

2.2.2 Annual Over-21 Insolation of Elemental Planes

The daily total over-21 direct radiation received by a plane
(DI) can be given as :

$$DI = \int_{H=\text{limits of exposure time (Appendix II)}}^{H=\text{over-21 period limit (Appendix ~~ix~~)}} I \text{ (equation iv) } dH$$

Similarly, the daily total over-21 diffused (DI_{DF}) and reflected
(DI_{RF}) radiation can be found :

$$DI_{DF} + DI_{RF} = \int_{H=\text{limits of exposure time (Appendix II)}}^{H=\text{over-21 period limit (Appendix ~~ix~~)}} I_{DF} + I_{RF} \text{ (equations ix) and xi) } dH \quad (\alpha = 0^\circ)$$

Doing the above calculations for the 21st of each month, and assuming that the 21st is a representative day of the month, the yearly total over-21 insolation of a plane (YI) can be given by :

$$\text{xii) } YI = (DI + DI_{DF} + DI_{RF}) \cdot \frac{365}{12}$$

Fig. II.5 is a flow chart of the computational process of the over-21 insolation of planes of orientations between 0° and 360° and inclinations between 0° and 90° varying in steps of 15° .

2.2.3 Insolation Index and Insolation Table

The values of (YI) calculated by equation xii) and given in Figs. II.6-8 for planes of various inclinations and orientations represent the over-21 insolation of unit areas of the planes. The over-21 insolation of a whole elemental plane is therefore equal to :

$$(YI) \cdot (\text{area})$$

This enables us to compare elements with different areas, inclinations and orientations from the over-21 insolation point of view. For this purpose the Insolation Index is constructed. It is a set of concentric rings divided radially. Each

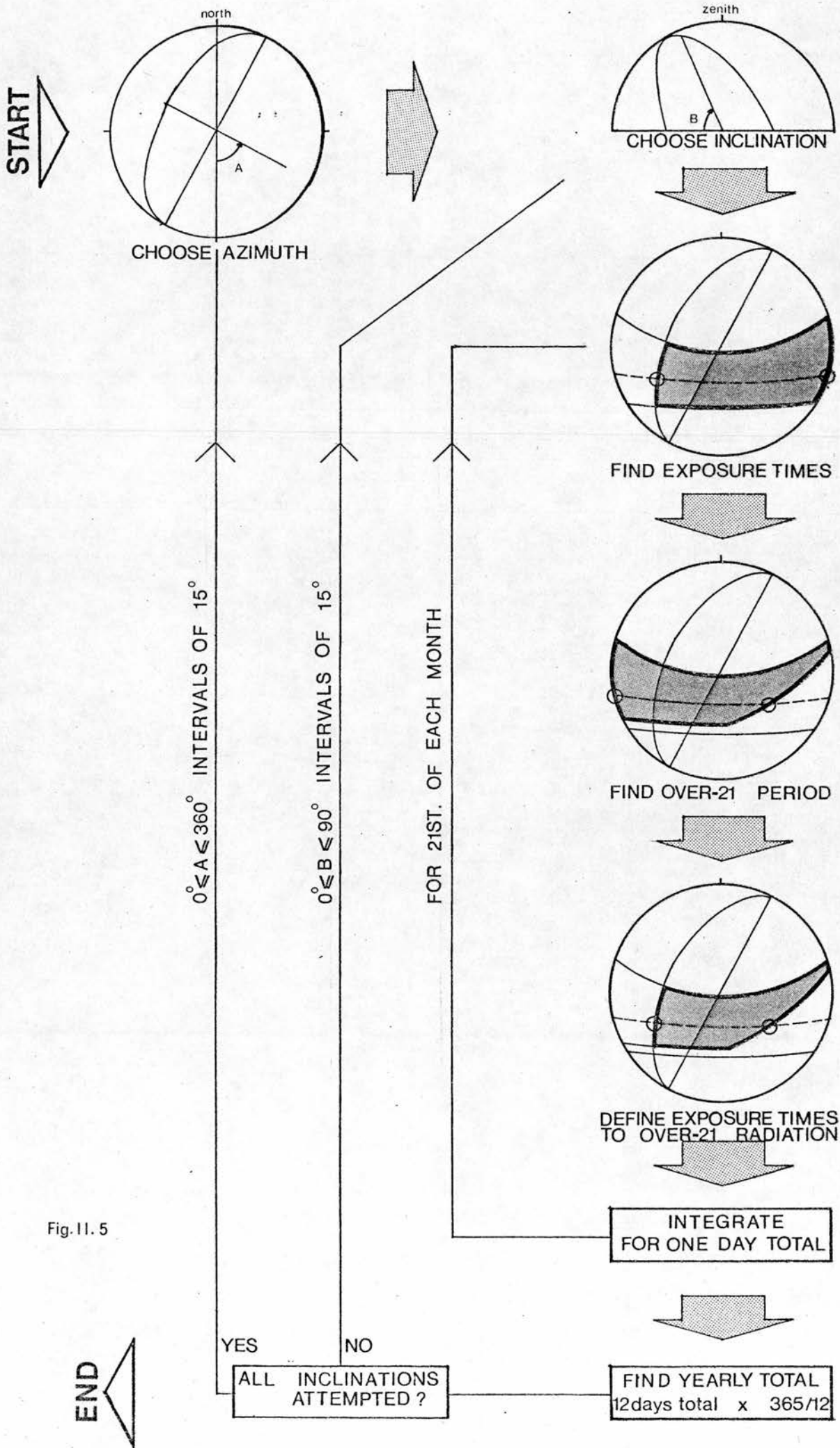


Fig. II. 5

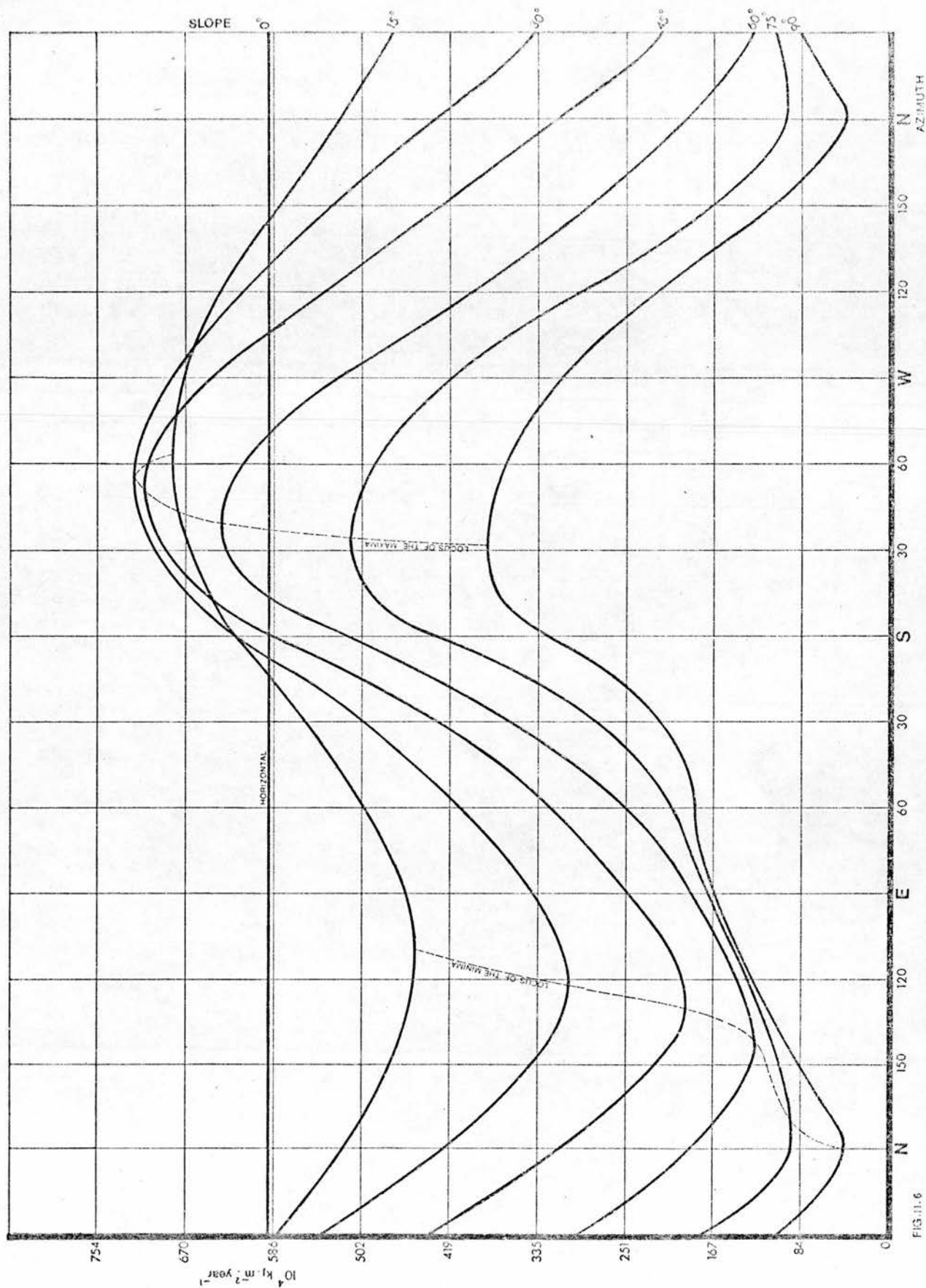
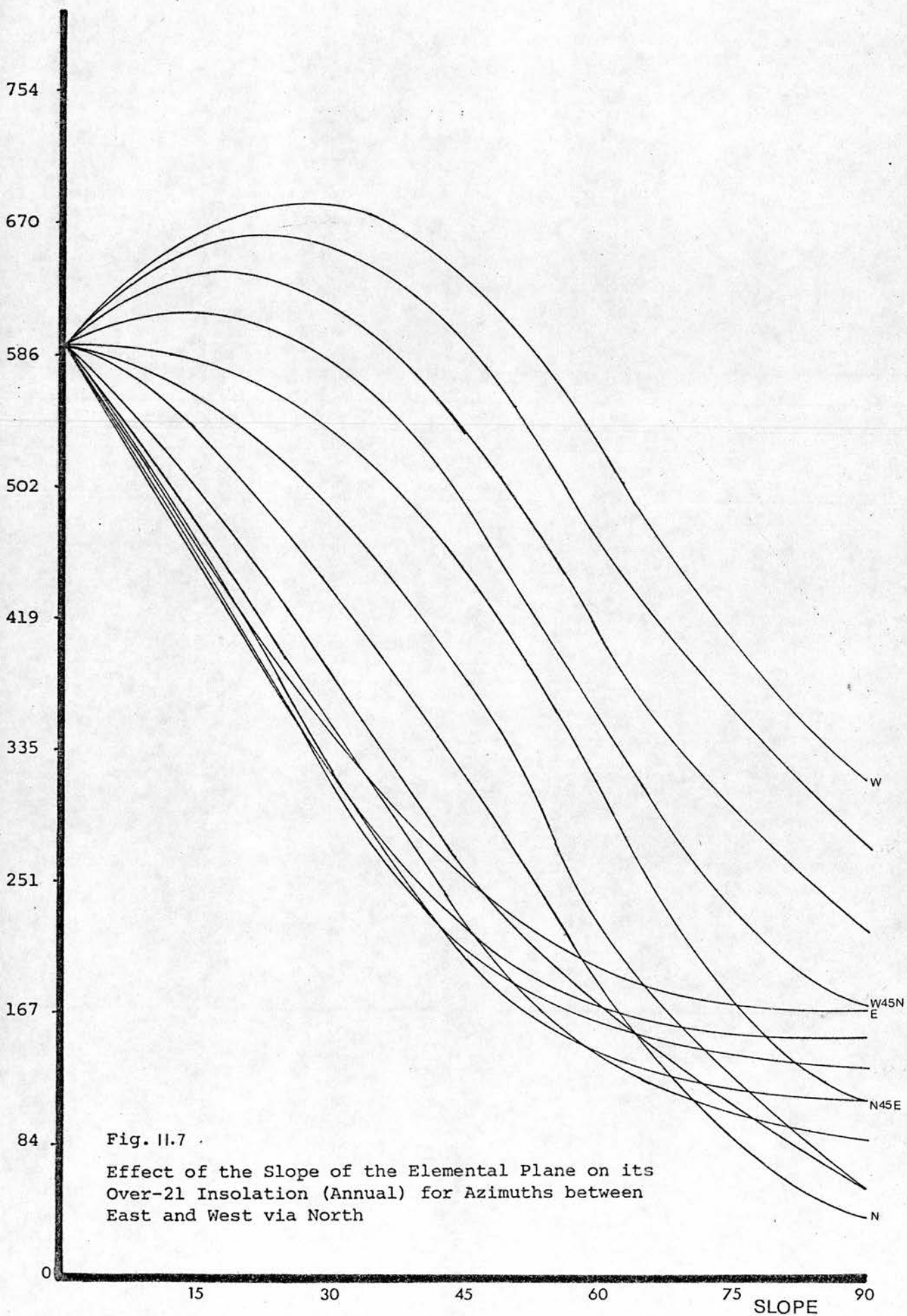


FIG.11.6
TOTAL ANNUAL OVER-21 RADIATION INCIDENT ON INCLINED ELEMENTAL PLANES COMPUTED FOR BAGHDAD.



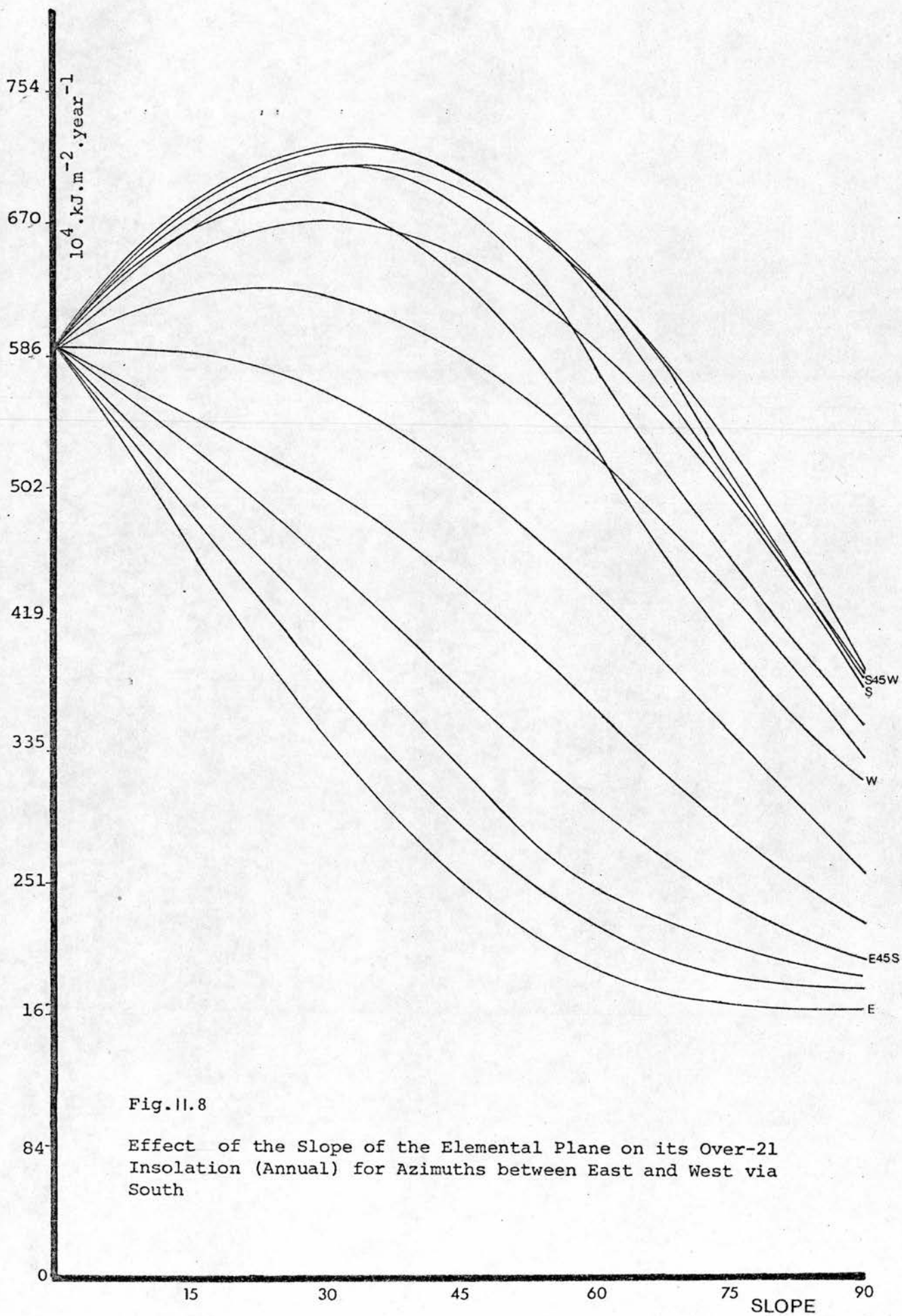


Fig.11.8

Effect of the Slope of the Elemental Plane on its Over-21 Insolation (Annual) for Azimuths between East and West via South

division, representing an inclination and orientation of a plane, contains its corresponding insolation number (IN), which is a simplified version of (YI), (Fig. II.9)

$$IN = YI/10^5$$

Used in conjunction with the Insolation Table (Fig. II.10) the index can yield insolation values for architectural forms by adding the (IN) · (area) multiples of all surfaces of the form in consideration.

Fig. II.11 is a contour analysis of the Insolation Index and Figs. II.12-13 show the applications of the Insolation Table in the evaluation of two possible orientations of a form.

2.2.4 Orientation Index and Plan Proportions Index

Taking the insolation numbers of vertical elements in the Insolation Index, and considering a rectangular plan as in Fig. II.14, let :

W	be the width of the plan
D	the depth of the plan
H	the height of the form
V	the volume
X1, X2	the insolation numbers of the two "W sides"
Y1, Y2	the insolation numbers of the two "D sides"
Ins	the total over-21 insolation of the four sides

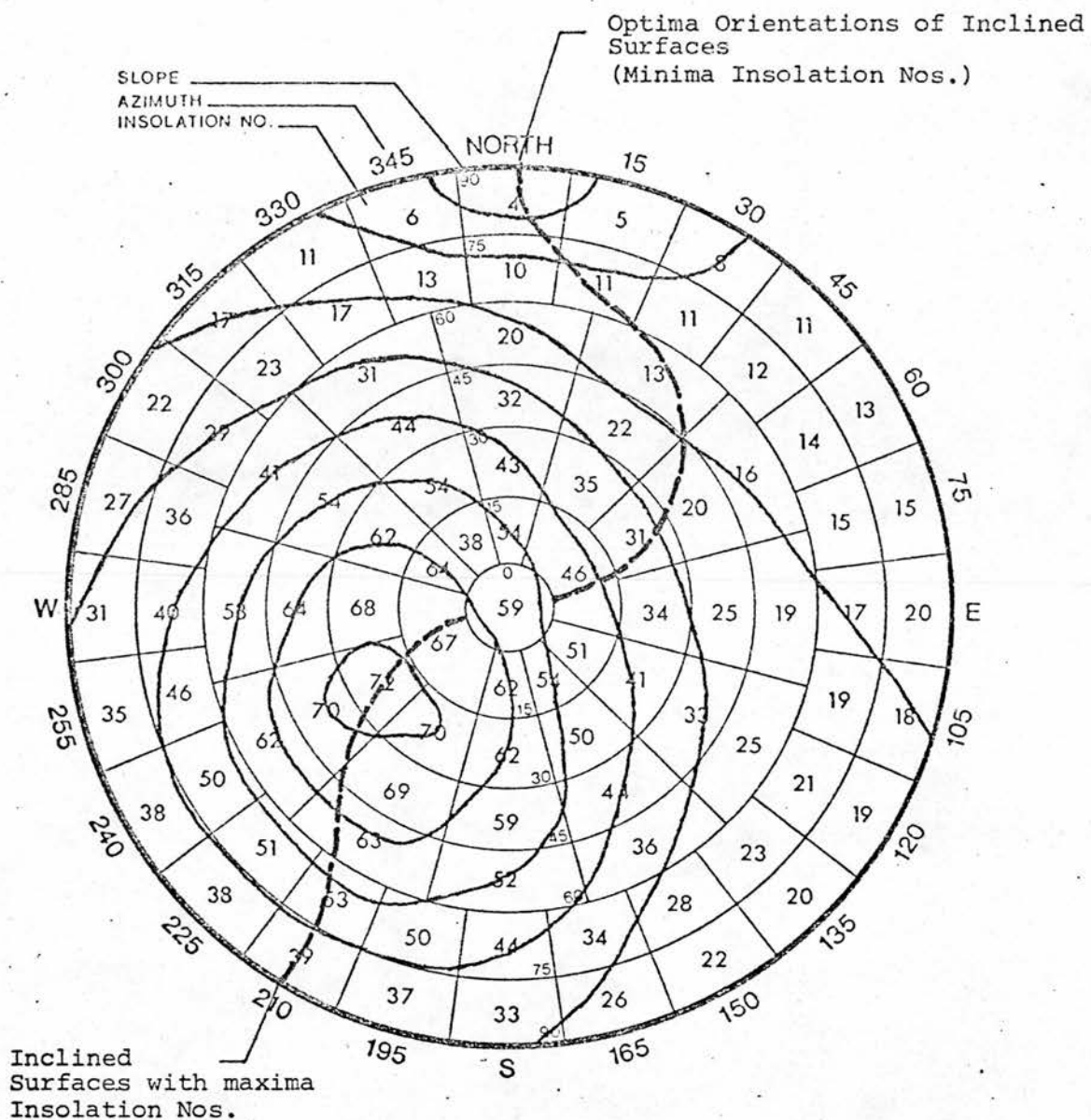
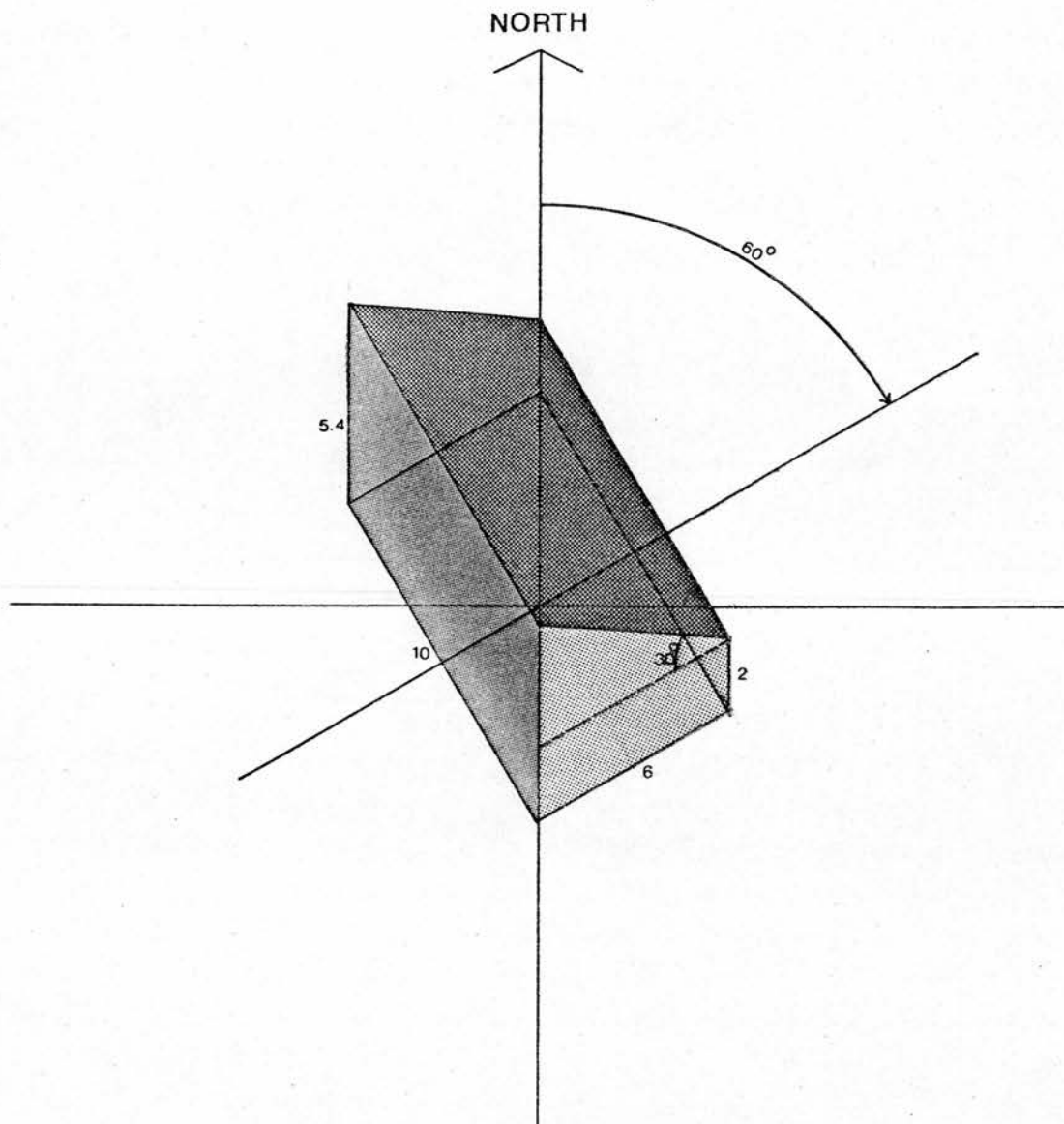


Fig. (11.11) Contour Analysis of the Insolation Index

The above diagrammatic analysis of the insolation index, clarifies the effect of the geometrical characteristics of an element on its over-21 insolation. It shows that inclined elements of north to north-east orientations have least insulations. The opposite is true of elements of south-west orientations.



SURFACE		AREA	INS.NO.	
azimuth	slope	A	YI	A YI
60	90	20	13	260
150	90	22.2	22	488.4
240	90	54	38	2052
330	90	22.2	11	244.2
60	30	69	31	2139
				sum
				5183.6

FORM INSOLATION NO. —————>

Fig. II.12 : Application of the Insolation Index and Table to Find the Form Insolation No.

$$\begin{aligned}\text{therefore } Ins &= H.W.X1 + H.W.X2 + H.D.Y1 + H.D.Y2 \\ &= H(W (X1 + X2) + D(Y1 + Y2))\end{aligned}$$

$$\begin{array}{lll}\text{Let} & X1 + X2 = X & (\text{axial orientation} \\ & Y1 + Y2 = Y & \text{numbers})\end{array}$$

Therefore

$$i) \quad Ins = H(W.X + D.Y)$$

$$\text{But} \quad W = V/D.H \quad \text{substituting in Eq. i)}$$

$$Ins = H(VX/D.H + D.Y)$$

By differentiation :

$$\begin{aligned}d(Ins)/d(D) &= H(-V.X/D^2.H + Y) \\ &= H.Y - V.X/D^2.H\end{aligned}$$

For minimum (Ins) :

$$d(Ins)/d(D) = 0$$

therefore

$$H.Y - V.X/D^2.H = 0$$

$$H.Y = V.X/D^2.H$$

$$D^2.H^2.Y = V.X$$

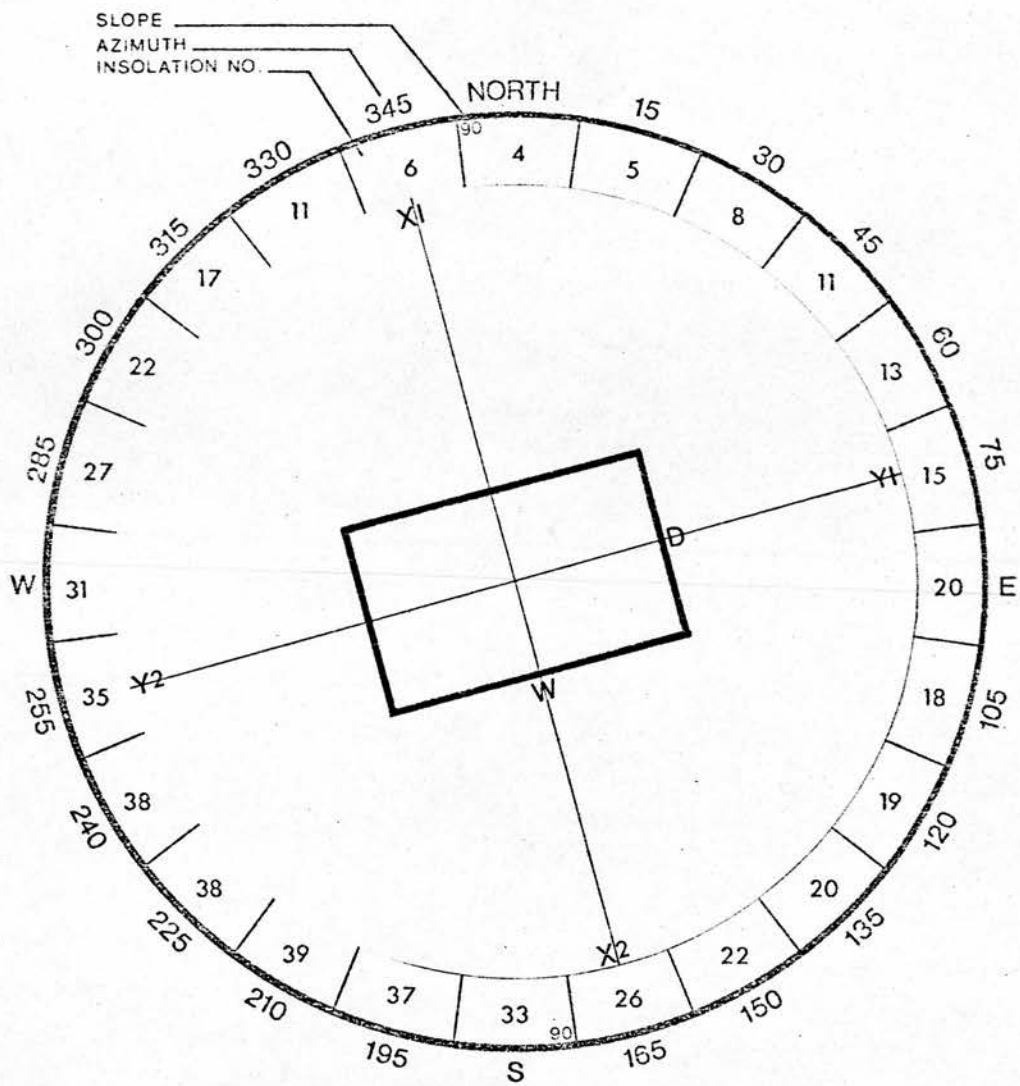


Fig. II.14

Insolation of Walls of a Rectangular Plan Building

but

$$V \leq W.D.H$$

therefore

$$D^2.H^2.Y = W.D.H.X$$

$$D.H.Y. = W.X$$

$$\text{ii)} \quad X/Y = D.H/W$$

since (H) is constant for a building with a horizontal roof:

$$\text{iii)} \quad \underline{D/W \propto X/Y}$$

Since all parameters in equation i) are positive,

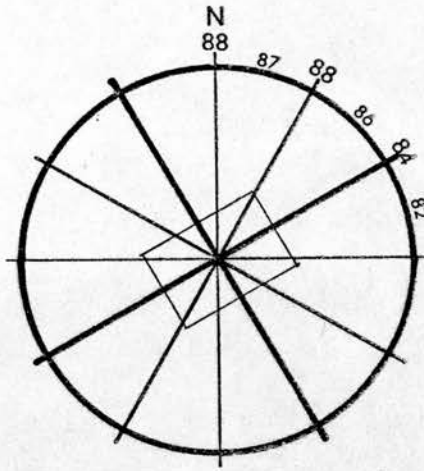
$$\text{iv)} \quad \text{Ins} \longrightarrow 0 \quad \text{when } x + y \longrightarrow 0$$

It is possible to conclude from the above that, according to iii) and iv), the insolation of the walls is minimum when :

A. The orientation is such that the sum of the two axial insolation numbers is minimum

and B. The ratio of the two dimensions of the plan is inversely proportional to the ratio of their respective axial insolation numbers.

As a result, the Orientation Index in Fig. II.15 and the Plan Proportions Index in Fig. II.16 were constructed. They are to be used in conjunction, the first for the decision on the orientation and the second on the proportions of the plan. It can be seen that by use of the recommended proportions for each axial orientation, a change of axial orientation can cause a change in the total insolation by less than 8%.

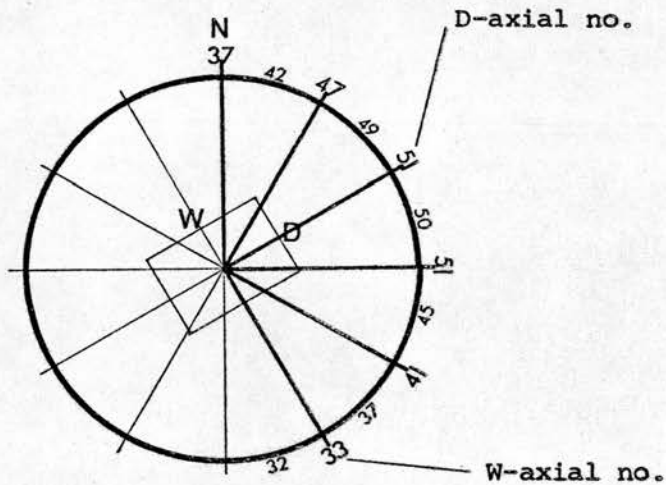


Orientation Index

Fig. II.15

Each two perpendicular axes represent one axial orientation of a rectangular plan form.

Optimum axial orientation has minimum number



Plan Proportions Index

Fig. II.16

Knowing the axial orientation of a rectangular plan, its optimum proportions can be found by :

$$\frac{D}{W} = \frac{\text{W-axial no.}}{\text{D-axial no.}}$$

CHAPTER III

DESIGN OF THE ELEMENT

1. The Opaque Element, External Colour,
Material Content and Composition

1.1 The thermal effect of the external colour and materials of the element on the internal thermal environment is discussed at length in Appendix V, in the context of the thermal mechanism of the building. It would be justified to state that, in general, the approach of researchers in dealing with these aspects of the thermal form reflects a stronger relevance to the field of building physics than to the process of architectural design. This conventional approach is one dependent on predictions built on conclusions which are derived from past experience. This is mainly due to the complexity of the non-steady state heat flow across the external elements of the building, which is caused by the vast fluctuation of the external thermal conditions and further complicated by the effect of the thermal capacity of the element.

In a generative approach, the role of the thermal properties of the element as a parameter of the thermal

form should be viewed as one of controlling the influence of the outside air temperature and solar radiation on the internal thermal environment. And therefore a relationship between the external and internal thermal environments, as well as the thermal form of the building through these parameters is essential.

1.1.1 Approaches with Generative Potential

The dependence of the internal temperatures of masonry houses on the mass of their structure was proved by Drysdale (1961) in Australia. He found a relationship between the weight of the external walls per unit external surface area (W_a), the outside and inside maximum air temperatures (T_o) and (T_i), and suggested the following relationship :

$$T_i = T_o - 0.044 W_a (T_o - 20) ^\circ\text{C}$$

where (W_a) is in kg/m^2 .

In homogeneous materials, the characteristic which dictates the thermal behaviour is the ratio of thermal conductivity and heat capacity. Considering the fact that this ratio and the average weight of masonry structures

are interrelated, Raychaudhuri and Chadhury (1961) made some experiments and found an empirical relationship similar to the one found by Drysdale :

$$T_i = T_o - 0.019 W_b (T_o - 16) ^\circ\text{C}$$

(W_b) in this case is the average weight of the whole structure, including the external and internal walls and the roof, per unit of the external surface area.

The generative character in the above mentioned equation is in the fact that it relates a building parameter to elements of the external and internal thermal environments. By substituting for (T_o) from data of the site in question, and for (T_i) by a value within the comfort range, it is possible to derive a design value for (W_b).

This relationship, however, holds true for homogeneous materials only and can be criticised from the point of view that it is derived from observations made mostly on 25 cm brick walls and an average weight 117.5 kg/m². Since it is common practice in some hot regions to use 25 cm walls as internal partitions and considerably heavier construction for external walls, the total construction can often get heavier than the one used for measurements. Moreover, the weight of the whole struc-

ture per unit external area can prove to be a difficult parameter to evaluate in design.

When considering the choice of suitable materials for a building in hot dry climate, three climatic factors have to be taken into consideration, the maximum and the daily amplitude of the air temperature and the amount of solar radiative heat absorbed by the external surface.

Air temperature and solar radiation can be evaluated according to their duration of effectiveness. Air temperature affects the external surface continuously throughout the day, irrespective of the geometry of the element, whereas solar radiation affects a horizontal element for an average of twelve hours a day, and vertical elements for much less.

The elemental thermal properties to be considered here are the thermal resistance and capacity, referred to here as the R and C values of the element. The function of the R value of the element is to moderate the flow of heat to the inside due to the rise in the external surface temperature. The required R value of the element is a function of the rise in external surface temperature due to its insolation and the increase in air temperature beyond a certain critical value.

Working along similar lines, and suggesting a critical air temperature value of 25°C , Givoni (1968, 1969) constructed the following formulae for predicting the required R values for walls (R_w) and roofs (R_f) :

$$R_w = 0.05 (T_o - 25) + 0.02 \left(\frac{a \cdot I_m}{12} \right)$$

$$R_f = 0.05 (T_o - 25) + 0.03 \left(\frac{a \cdot I_m}{12} \right)$$

where $T_o - 25$ is the rise in maximum outside air temperature above 25°C

$\frac{a \cdot I_m}{12}$ is the rise in external surface temperature due to insolation

a is the absorptivity of external surface

I_m is the maximum intensity of radiation incident on external surface

The effect of the thermal capacity, on the other hand, is to moderate the influence of the fluctuation of outside air temperature on the internal thermal environment. Relating the daily outside air temperature amplitude, the maximum intensity of incident solar radiation and the absorpsivity of the external surface, Givoni set the following formulae for predicting the required C values for walls (C_w) and roofs (C_r) :

$$C_w = 2.5(T_o - t_o) + 1.0\left(\frac{a \cdot I_m}{12}\right)$$

$$C_r = 2.5(T_o - t_o) + 1.5\left(\frac{a \cdot I_m}{12}\right)$$

where $T_o - t_o$ is the outside air temperature amplitude.

The above formulae represent a rare attempt to predict mathematically the necessary thermal properties of the elements of the building in hot climates. Furthermore, they apply to both homogeneous and multi-layered elements. Yet they are far from being of easy use to the designer, since they require values for the maximum intensity of solar radiation incident on the element, and the interpretation of the R and C values into materials and building construction. Moreover, their application is limited to horizontal and vertical elements only.

1.2 Development of the R and C Value Formulae

A study of the two R value formulae reveals that they can be combined in the following form :

$$i) \quad R = \frac{I}{100} (5 T_o + J_r \cdot a \cdot I_m - 125)$$

where (Jr) is a factor varying with the inclination of the building element between a maximum value of $1/4$ for horizontals and a minimum of $1/6$ for verticals.

For building elements with various inclinations the following relationship can be constructed :

$$\text{ii)} \quad J_r = \frac{1}{1080} (270 - \beta)$$

Similarly, the equations for predicting the required (C) value of a building element can be written as :

$$\text{iii)} \quad C = \frac{1}{10} (25(T_o - t_o) + J_c \cdot a \cdot I_m)$$

$$\text{iv)} \quad J_c = \frac{1}{216} (270 - \beta)$$

Eliminating Jr and Jc from i) and iii) we get :

$$\text{v)} \quad R = \frac{1}{100} \left[5(T_o - 25) + \frac{270 - \beta}{1080} \cdot a \cdot I_m \right] \frac{\text{m}^2 \text{h}^\circ \text{C}}{\text{kcal}}$$

$$\text{vi)} \quad C = \frac{1}{10} \left[25(T_o - t_o) + \frac{270 - \beta}{216} \cdot a \cdot I_m \right] \frac{\text{kcal}}{\text{m}^2 \text{C}}$$

Using SI units :

$$\text{vii)} \quad R = 43 \times 10^{-3} \left[(T_o - 25) + \frac{270 - \beta}{6280} \cdot a \cdot I_m \right] \text{ m}^2 \cdot \text{C/W}$$

$$\text{viii)} \quad C = 1047 \left[(T_o - t_o) + \frac{270 - \beta}{6280} \cdot a \cdot I_m \right] \text{ J/m}^2 \cdot ^\circ\text{C}$$

1.2.1 Selection of Data for the R and C Values Formulae

One of the problems confronting the user of these equations is the choice and computation of the data involved, since no particular method has been suggested.

A. Maximum Outside Air Temperature (To) and Minimum Outside Air Temperature (to)

In studying the climate of Baghdad in Appendix VIII, we notice in Fig. AVIII.3 that the air temperature during the five successive months of May to September stays at values above 20°C . This, as can be seen in Fig. IV.1 of Chapter IV, is the lowest air temperature value for comfort.

Taking these values as representative of the hot

period of the year, it is possible to derive the required data by averaging the values of each of the mean maxima and minima air temperatures. This yields the following results :

$$T_o = 40.1^{\circ}\text{C}$$

$$t_o = 24.2^{\circ}\text{C}$$

$$T_o - t_o = 15.9^{\circ}\text{C}$$

B. Maximum Intensity of Incident Radiation (I_m)

Measured information on solar radiation is generally sparse. It can be seen from Appendix VIII that the only available measured data for Baghdad is that of monthly mean daily total radiation incident on a horizontal surface. In light of this, values for (I_m) will have to be computed.

Equations iv), ix), xi) in Chapter II provide a method for calculating the intensity of solar radiation incident on an elemental plane. By making the calculation for each possible hour of insolation it is possible to find the hourly maximum intensity. The values derived by this approximation are considered

here as sufficient for the purpose of this study.

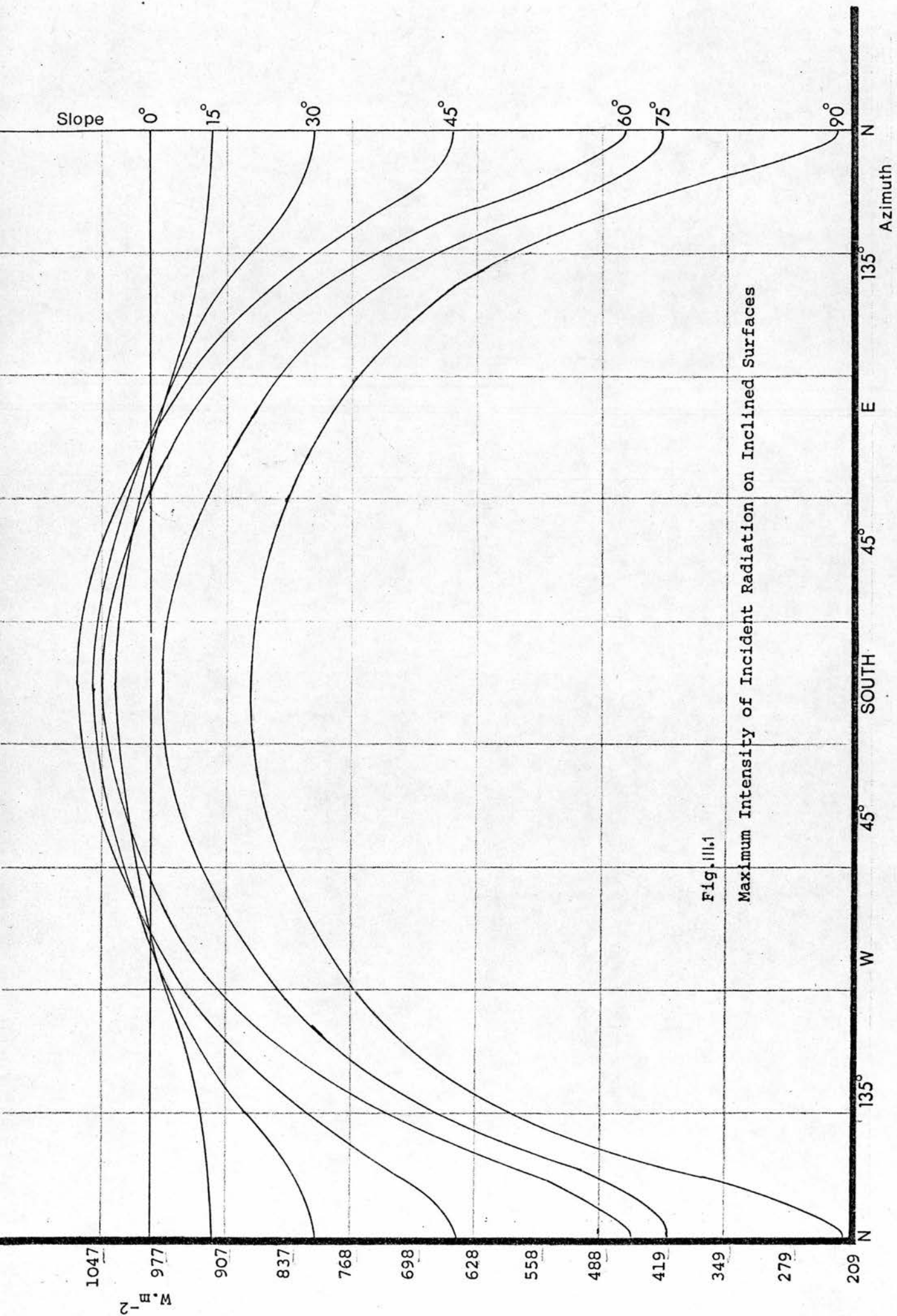
Results of these computations for vertical, inclined and horizontal elements with varying orientations are presented in Fig III.1.

C. Absorptivity of External Surface (a)

Table A V.1 in Appendix V gives the reflectivity values of a variety of surfaces used in building practice. Considering that building surfaces vary between the highly reflective whitewash and the rough brick treatment, the values of 15, 30, 45 and 60% are considered here as representative, and suitable for the calculations in question.

1.3 Required R and C Values for Building Elements in Baghdad

Equations vii) and viii) are here solved for building elements varying in inclination between 0° and 90° and in orientation between 0° and 360° , both in steps of 15° , and in external absorptivities between 15 and 60% varying in steps of 15%. Using the climatic data derived above, the R and C values found are those necessary for elements of buildings in Baghdad (Figs. III. 2-5)



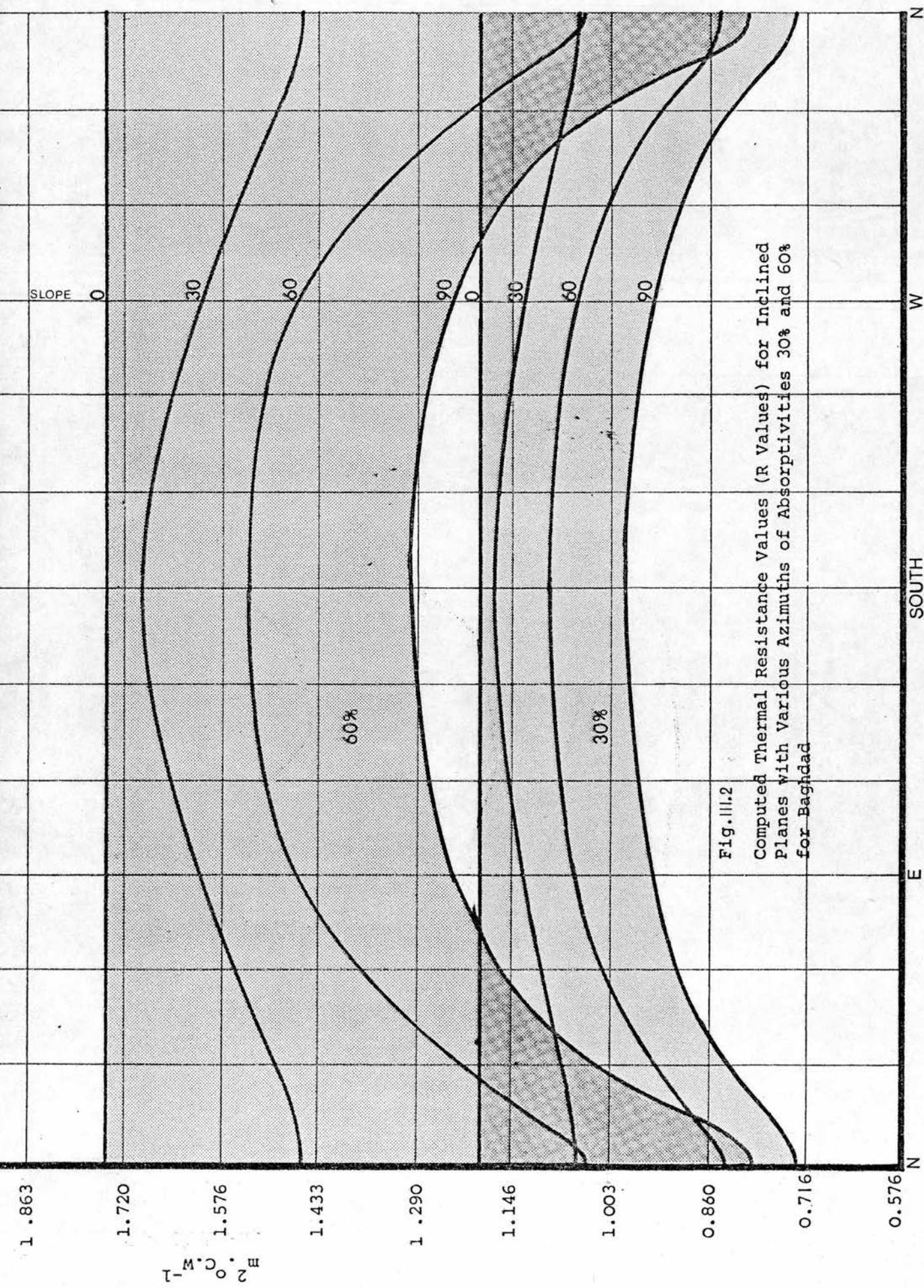


Fig. III.2
Computed Thermal Resistance Values (R Values) for Inclined
Planes with Various Azimuths of Absorptivities 30% and 60%
for Baghdad

1-20°C

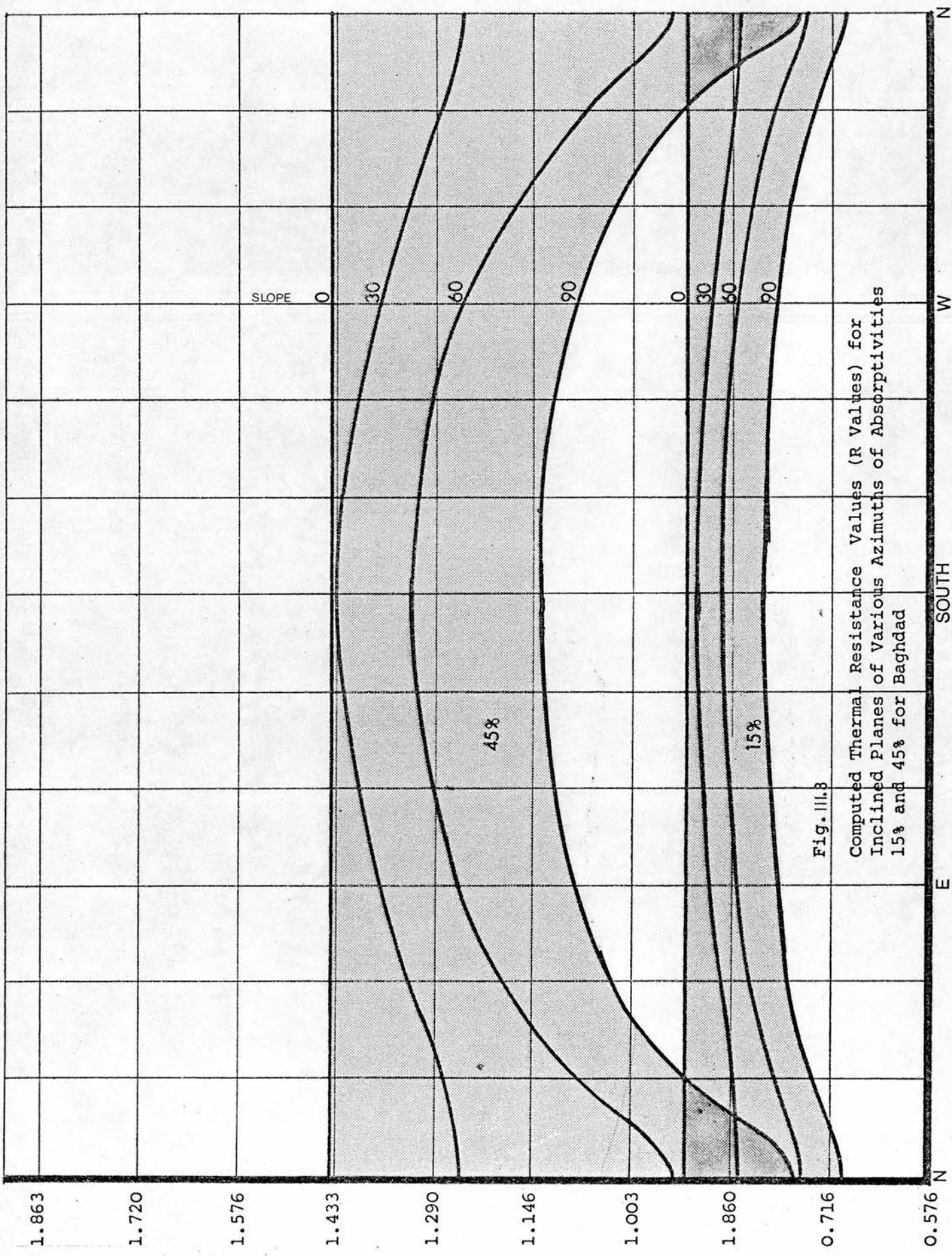
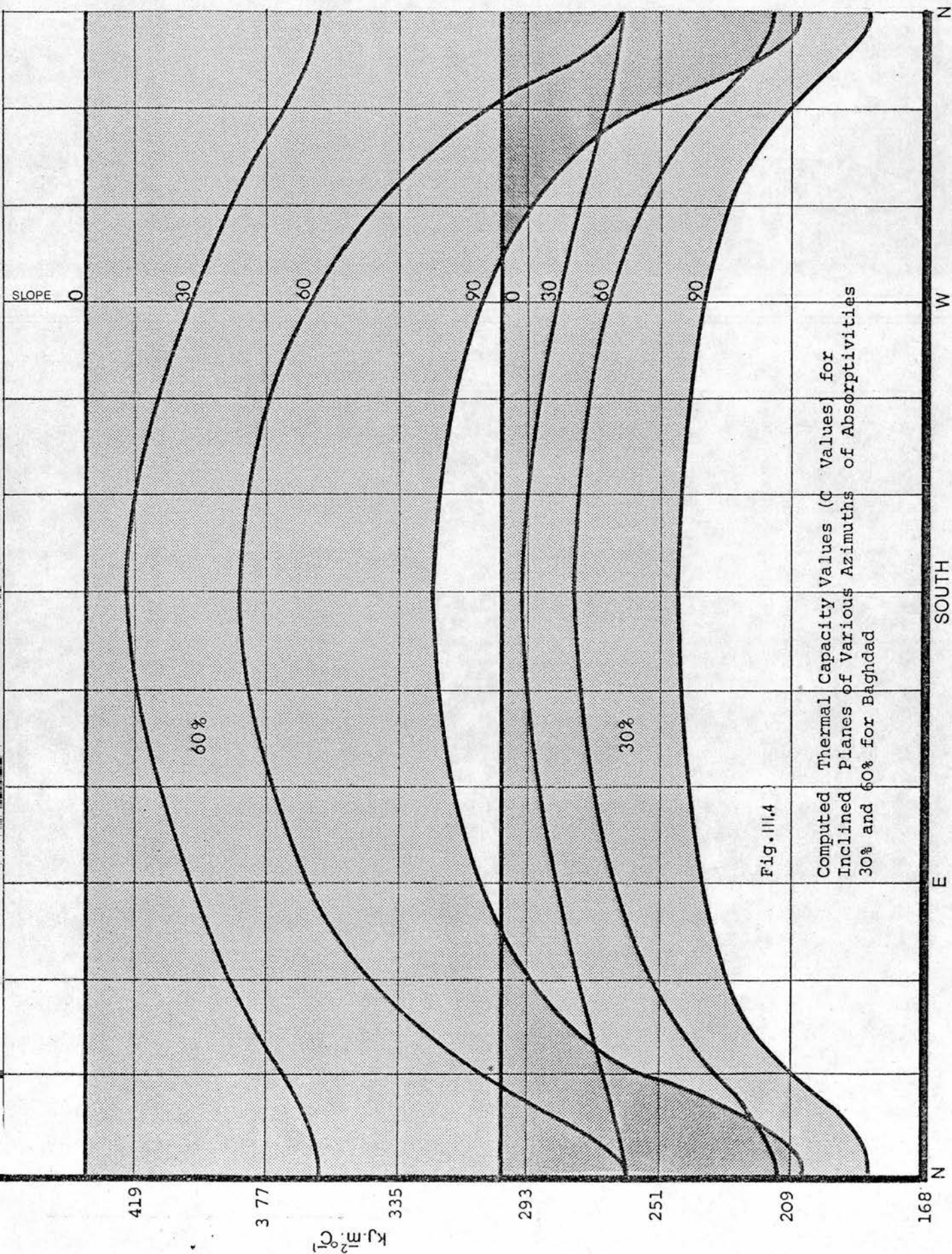


Fig. III.8

Computed Thermal Resistance Values (R Values) for Inclined Planes of Various Azimuths of Absorptivities 15% and 45% for Baghdad



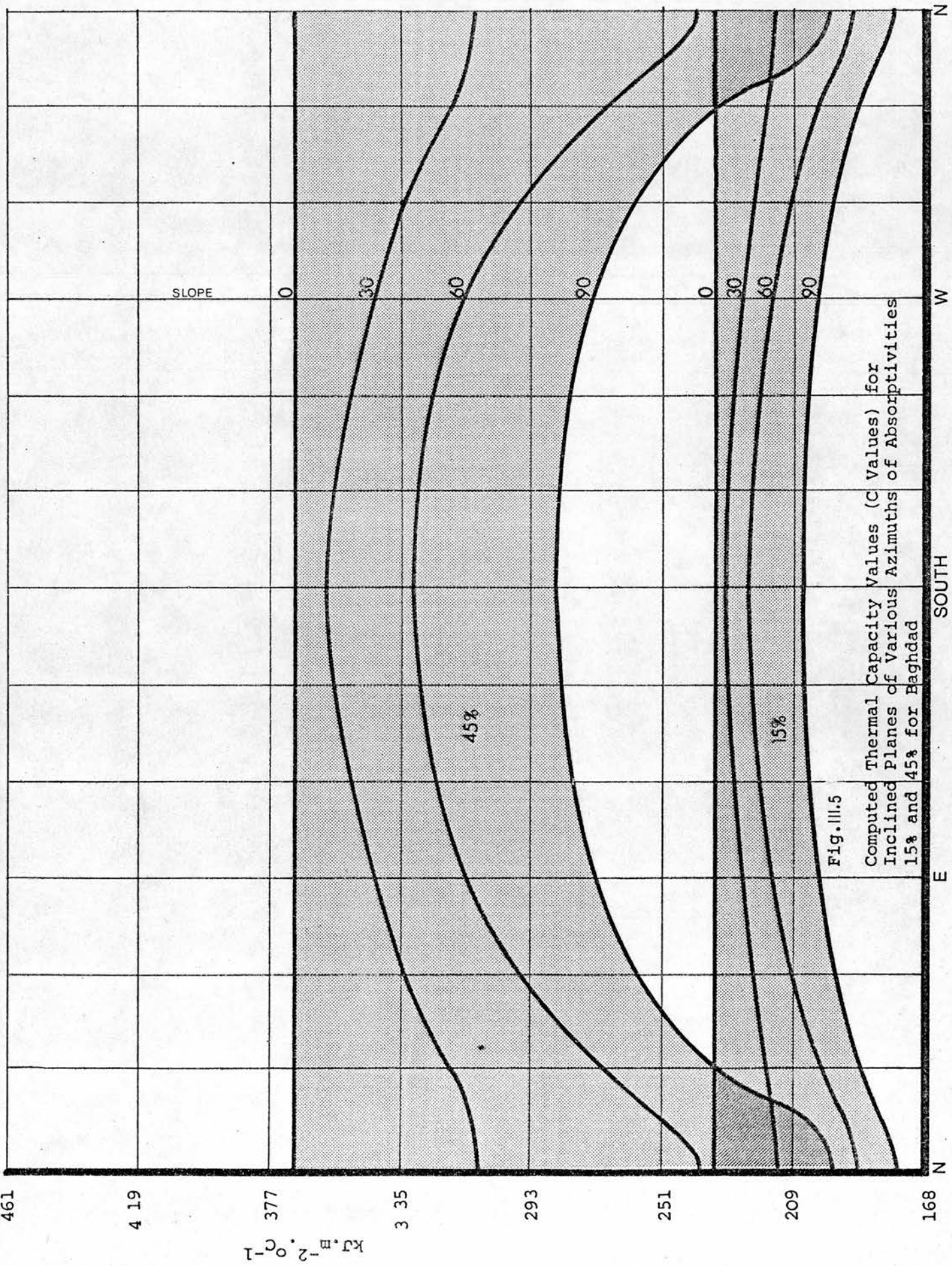


Fig.III.5
Computed Thermal Capacity Values (C Values) for
Inclined Planes of Various Azimuths of Absorptivities
15% and 45% for Baghdad

1.4 Systematisation of the R and C Values Generation

1.4.1 Reflectivity Chart

It is clear from Figs. III.2-5 that the R and C values are a function of the external surface reflectivity. Any generation of these values will therefore have to be preceded by a decision on the nature of the external surface. In order to make a comparative evaluation easier, the Reflectivity Chart in Fig III.6 is constructed for reflectivity values of a variety of surfaces extracted from Table A V.1 in Appendix V.

1.4.2 R and C Values Index and R and C Values Index Range

In attempting to express R and C in one parameter, the product RC has been used by Givoni (1969) in representing the thermal properties of materials. This method, easy to apply as it may seem, has considerable disadvantages, since a wall with high R and low C values and another with moderate R and C values can have similar RC values, and since the separate thermal effects of R and C have a difference which is of major importance in a climate of a hot dry nature. Because of this it is considered here as advantageous to express the values as two separate

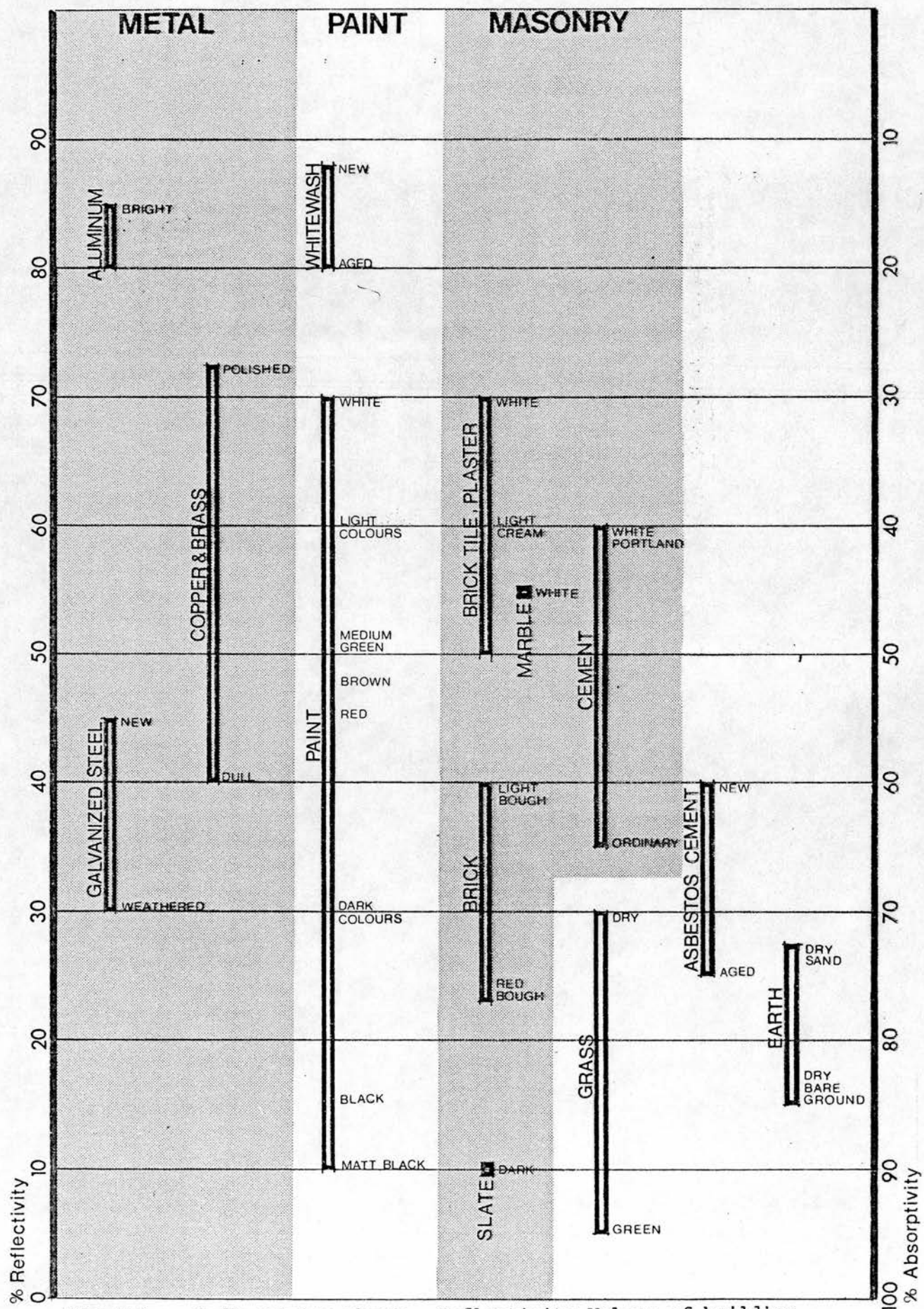


Fig. III.6

Reflectivity Chart. Reflectivity Values of building surfaces

parameters.

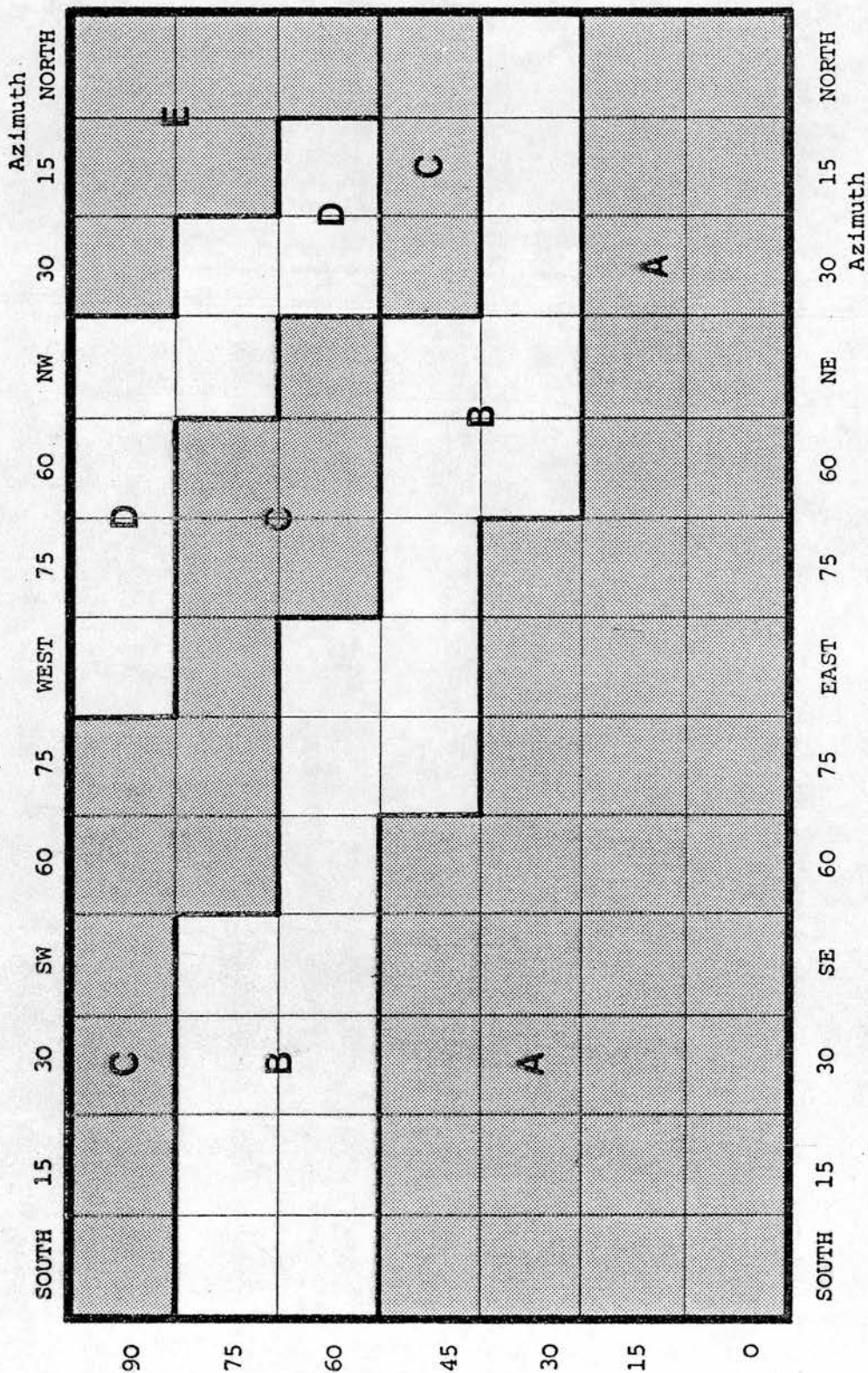
To make the generation of the R and C values systematic, the index in Fig. III.7 is constructed. It is based on the classification of elements, defined by their geometries i.e. inclinations and azimuths, according to their R and C values, into five categories labelled A to E.

The R and C value Index Range in Fig. III.8 on the other hand, states the R and C values of each category according to the reflectivity of the external surface.

1.5 Interpretation of the R and C Values into Building Construction

1.5.1 C Value Chart and R Value Chart

In order to make the predicted R and C values readily usable, an interpretation into required types of construction and material of building elements will have to be made. Using the fact that insulating materials can be applied with little effect on the C value of an element, the procedure used here starts with the choice of the material and its thickness giving the required C value, the next step is to find its R value and supplement any shortage with additional insulating material.



R & C VALUES INDEX

Fig. III.7 The categorization of the Thermal Resistance and Thermal Capacity requirements for elements of various inclinations and azimuths

REFLECTIVITY %	A	B	C	D	E	
	R	C	R	C	R	C
85	0.90	0.86	0.82	0.77	0.72	
	228	219	208	197	185	
70	1.15	1.07	0.98	0.89	0.79	
	291	271	250	227	200	
55	1.4	1.28	1.15	1.02	0.86	
	353	324	292	258	220	
40	1.66	1.49	1.31	1.15	0.93	
	406	385	335	293	240	

R & C VALUES INDEX RANGE

Fig. III.8 Key to the R & C Value Index according to the reflectivity of the external surface of the element

Fig. III.9 gives the R and C values of a variety of thicknesses of building materials. Fig. III.10 gives the R values of a range of thicknesses of insulating materials. These charts use information collected in Appendix V, Table V.2-3. The systematic use of the charts and indices discussed above is further illustrated in the context of the complete generative model in Chapter VI.

2. The Transparent Element, Its Insolation and Design

2.1 General

By a study of section 2. in Appendix V it is possible to draw conclusions concerning the design of transparent elements and its determinants.

The provision of light in the designed space and the visual link with the outside, and the important thermal effect transparent elements can have on the internal thermal environment, are influential forces acting in opposite directions affecting the decision on the provision and size of a glazed window in a particular orientation. Assuming

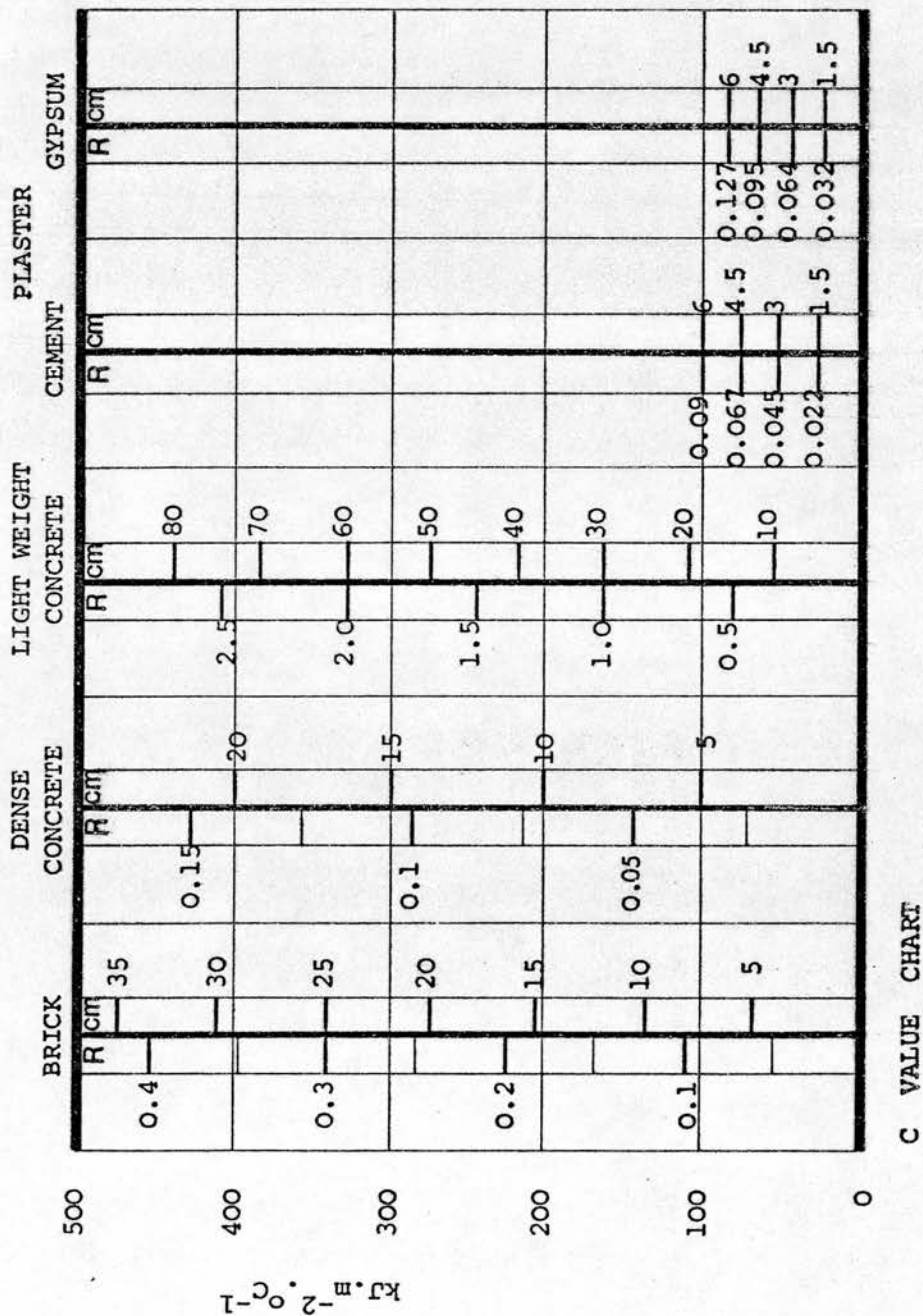


Fig.111.9 The thermal capacities of a range of thicknesses of various bulk building materials.

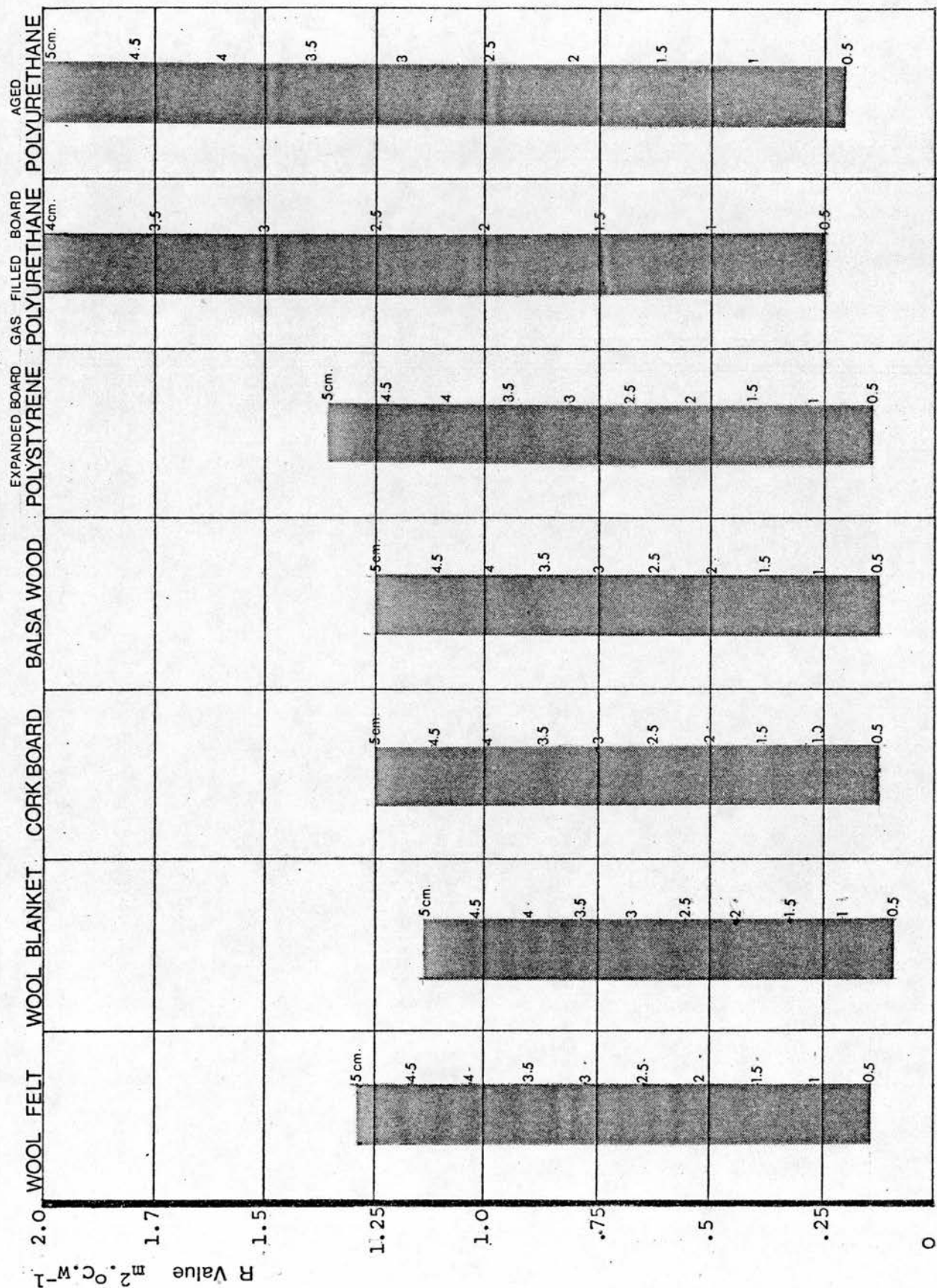


Fig. III.10 The Thermal Resistances of a Range of Thicknesses of Various Insulating Materials

little variation of air temperature and surface reflectivities around the building, the orientation of well shaded windows can be taken as a matter of no significant thermal influence. And apart from the window area, in which case the smallest satisfactory area meeting the non-thermal requirements can be recommended, the only other thermally influential characteristics of the window are the thermal properties of the glazing which variety has different effects on the transmission of radiative and conductive heat.

2.2 Shading Chart and Shadow Angle Protractor

Owing to factors like the direct transmission of radiative heat to the internal space during the over-21 period and the green-house-effect, incidence of over-21 direct solar radiation, which has previously been discussed as undesirable over external elements, can be assumed to have similar or worse effects when considering internal elements.

The design of appropriate shading devices to intercept direct radiation through consideration of the earth-sun relative movement has led to the development of several techniques of which the sun-light rule (Kruger, 1959) is

one which, comprehensive and adaptable though it might be, has developed into a complicated instrument making it cumbersome to use. The most popular of these techniques has proved to be the Shadow-Angle Protractor, which is a semicircular transparent instrument. This is used in conjunction with the Shading Chart, which is basically a solar chart representing the solar paths of the 21st of each month of the year for a particular latitude (see Appendix VIII, Fig. AVIII.2), with the shading period of the year plotted on it. The method predicts the required horizontal and vertical shadow angles by superimposition of the protractor on the chart. The orientation of the window is represented by that of the protractor's base line. This procedure, although simple and easily applicable, has been used in a crude manner. A solar chart is representative of the apparent sun paths overlapped for the two halves of the year defined by June 21st and December 21st. The shading period for the second half of the year has usually been used in the process. Shading devices designed accordingly automatically take care of the shading period of the winter part of the year but have the disadvantage of obstructing a considerable amount of the desirable radiation of the winter half of the year. A better use can be made of this method by using a solar

chart with shading periods of both parts of the year indicated, allowing for the use of shading devices adjustable between maximum shadow angles, given by the summer period shading area, and minimum ones given by the winter period shading area. A Shadow-Angle Protractor and a Shading Chart plotted according to this method for Baghdad are ~~illustrated~~ illustrated in Chapter VI, pages VI.21-22, as parts of the generative model. Fig. III.11 illustrates their application for a window orientation of S.15°E.

2.3 Heat Exchange Properties of Glazing

The properties control the exchange between the internal and external thermal environments through a glazed element of two kinds of heat, radiative and conductive.

Glazing Chart

The radiative heat exchange is dependent on spectral properties of glass and the angle of incidence of radiation on it. Fig. A V.6 in Appendix V displays a set of curves relating the angle of incidence to the radiative heat transferred, whether directly or after absorption, of a variety of glazing types. This information, valuable to the

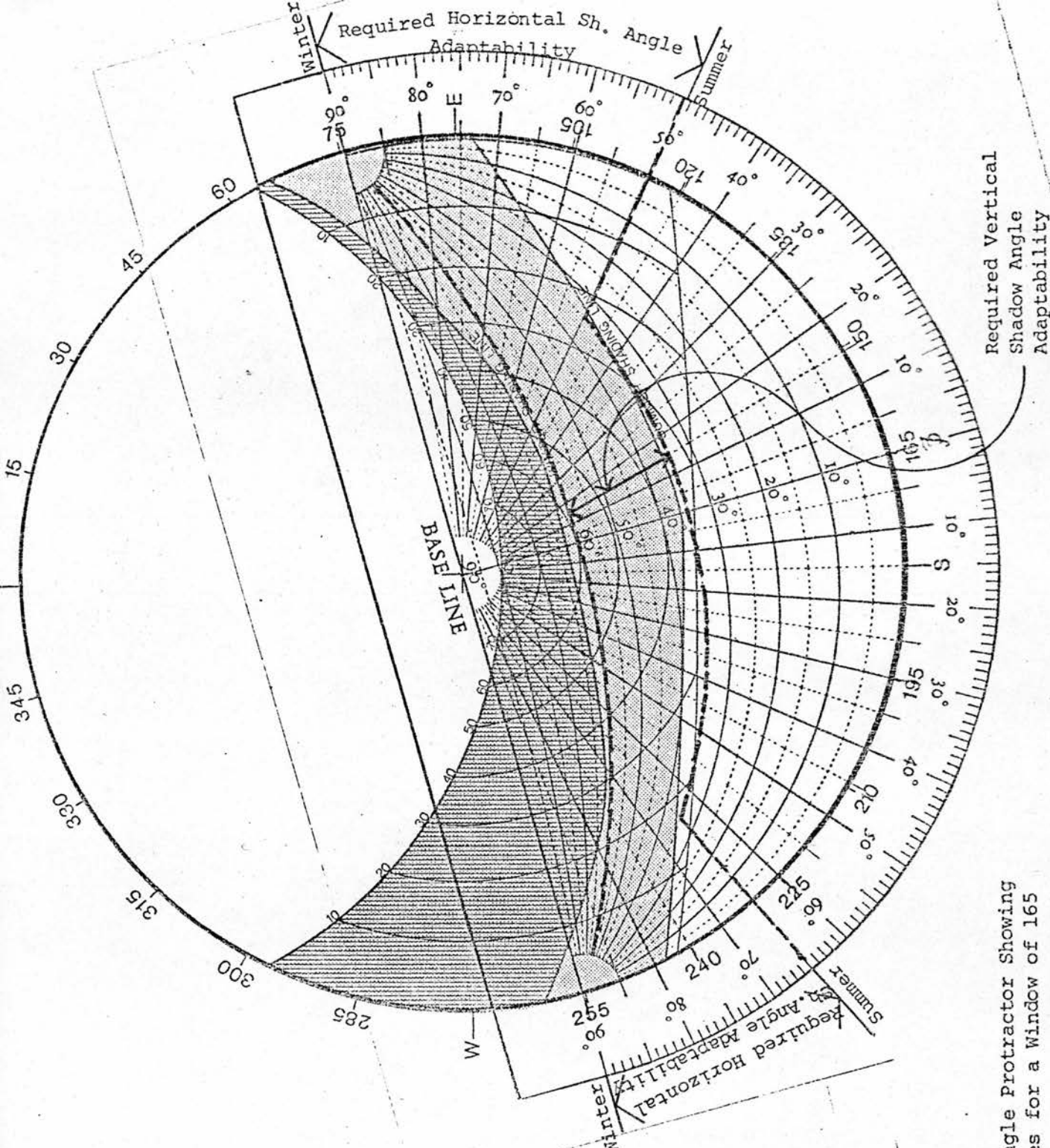


Fig. III.11

The Shading Chart and the Shadow Angle Protractor Showing the Winter and Summer Shading Angles for a Window of 165 orientation and the Required Adaptability of the Shading Device.

designer as it is, is presented in a form which makes comparative evaluation of different kinds of glass by the designer a confusing task.

By taking angles of incidence up to 60 degrees, the Glazing Chart in Fig. III.12 was composed for nine types of single and double glazing. The transfer level indicates the proportion of total radiative heat transferred to that incident on the glass.

The conductive heat exchange of glazing is controlled by its R and C values. The C value of glazed elements is negligible, but the R value is a function of the construction of the element. Double glazing with 2-10 cm air gap has an R value which is comparable to that of a 16 cm clay brick (see Appendix V, page A V.30). This, as can be seen from the first part of this chapter, might meet a good part of the R value requirements since the shading of the window will allow for prediction of smaller R and C values than those required for the non-shaded elements. In this light, a guide to the designer can be made in the form of a recommendation to use multiple glazing. A decision on this matter will have to depend on the designer's evaluation of the economical factors involved.



Fig. III.12 The Glazing Chart

CHAPTER IV

FURTHER CONTROL OF THE INTERNAL THERMAL ENVIRONMENT

In severe climatic conditions there is a critical point up to which good thermal design using conventional techniques can produce internal thermal comfort, and beyond which other means of thermal control have to be considered. The extent and nature of this control can be evaluated according to the expected deviation of the internal conditions from thermal comfort.

1. Environmental Limits for Thermal Comfort

By referring to Appendix IV, one can draw the following conclusions concerning the thermal comfort of man in a hot dry climate :

- A. Highest comfortable dry-bulb air temperature is 26°C with temperatures up to 28°C being comfortably warm.
- B. Lowest comfortable dry-bulb air temperature is 21°C with temperatures down to 20°C being comfortably cool.
- C. Highest comfortable vapour pressure is 17 mm Hg beyond which dehumidification is necessary.

- D. Lowest comfortable vapour pressure is 8 mm Hg below which humidification is necessary.
- E. Temperature of 28 to 30°C can be made comfortable or semi-comfortable by the application of air movement of up to 1 m/sec.
- F. Temperatures of 18 to 20°C can be considered comfortable to semi-comfortable with the existence of a mean radiant temperature of up to 22°C.

The above conclusions are represented graphically in Fig. IV.1 by a dry-bulb temperature/relative humidity graph.

2. Physiological Evaluation of the Climate of Baghdad

By using values of a combination of elements representative of the daily and annual cycle of the climate of a certain locality, and by use of the comfort diagram in Fig. IV.1 it is possible to evaluate the external thermal conditions from a physiological viewpoint.

Considering the climate of Baghdad, this can be done by the use of simultaneous values of dry-bulb temperatures and relative

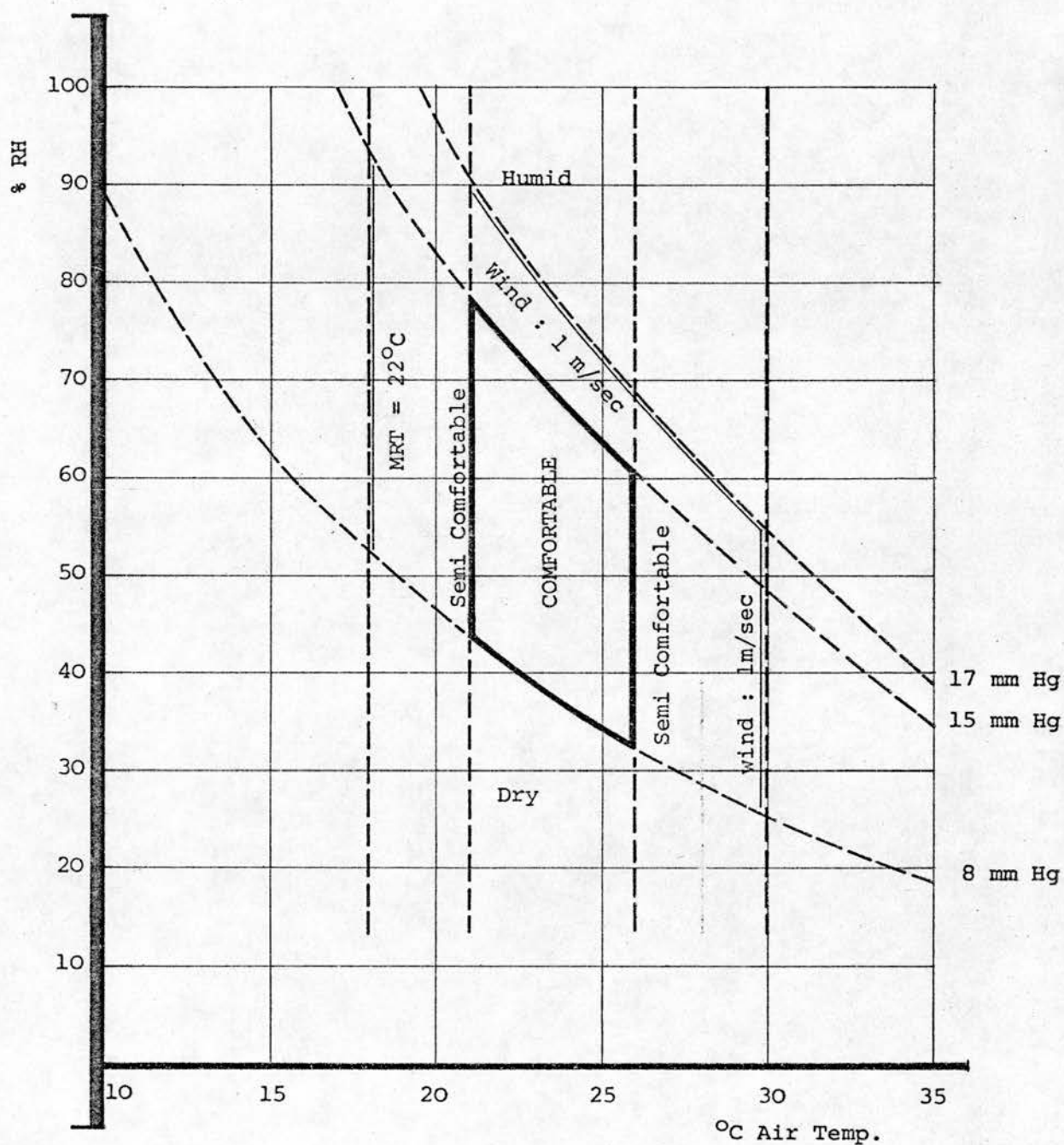


Fig.IV.1

The Thermal Effect of the combined climatic elements on man in the shade in a hot-dry climate and the corrective effect of wind and mean radiant temperature.

humidities of three hours intervals, of twelve average monthly days. The values corresponding to each interval are then checked in the comfort diagram where a conclusion can be made predicting the climatic corrections needed to restore comfort. By this process the chart in Fig. IV.2 is constructed. It expresses six thermal conditions, cold, hot, comfortable and comfortable with a condition of air movement, humidification or both. It is worth noting here that the chart represents conditions in the shade. Exposure to the sun in winter days is likely to balance the cooling effect of a considerable amount of their air temperatures. Being concerned with the external thermal environment, this chart can be used in the design of open spaces by consideration of the times of use of the spaces as well as their climatic design.

3. Complementary Thermal Requirements Chart and Natural Ventilation Chart

It is possible to define the function of the thermal form as acting as a corrective filter to the external environment in a way corresponding with the recommended adjustments presented by Fig. IV.2. But, as has been discussed above, the corrective effect of the building is limited. To be able to predict the extent and nature of any needed further control of the internal thermal environment,

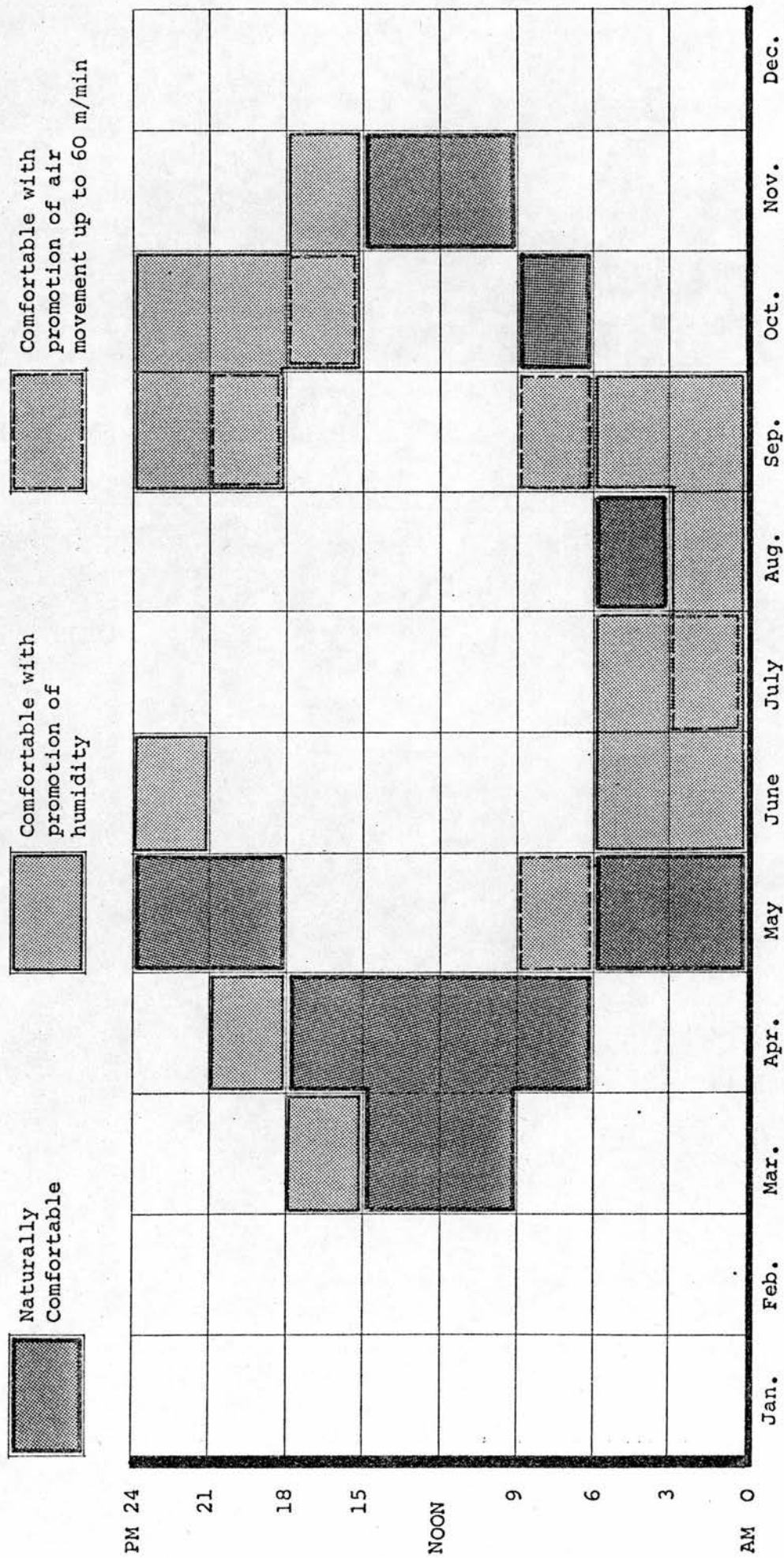


Fig. IV.2

An evaluation of the climate of Baghdad from a physiological viewpoint

we must define the limits of this corrective effect.

Fig. IV.3 shows the temperature-humidity comfort combinations plotted against climatic data for Baghdad represented by two rings being the paths of the monthly mean minima and maxima. The severity of the fluctuation of the climatic conditions is evident in the diagram and is shown to vary annually in temperature between 4°C and 44°C , and in humidity between 12% and 89%. It is also of interest to note that conditions of the hot part of the summer generally follow the line of 8 mmHg, and the biggest deviation is that of the minima to a $5\frac{1}{2}$ mmHg vapour pressure. As has been concluded above, such conditions are considered uncomfortable and are likely to cause dryness of the lips and mucous membranes, but assuming that with no ventilation internal vapour pressure is 2 mmHg higher than outside, we find that humidification is mainly required during the cold nights of the winter. Humidification during the hot period can be provided by the use of evaporative coolers, but the effectiveness of their cooling is limited since a high increase in relative humidity will introduce a lower ceiling for comfortable air temperatures. Thus in severely hot conditions, mechanical non-evaporative cooling is required.

By predicting the internal thermal conditions, Givoni (1969) extended the conceivable comfort area to the times when external

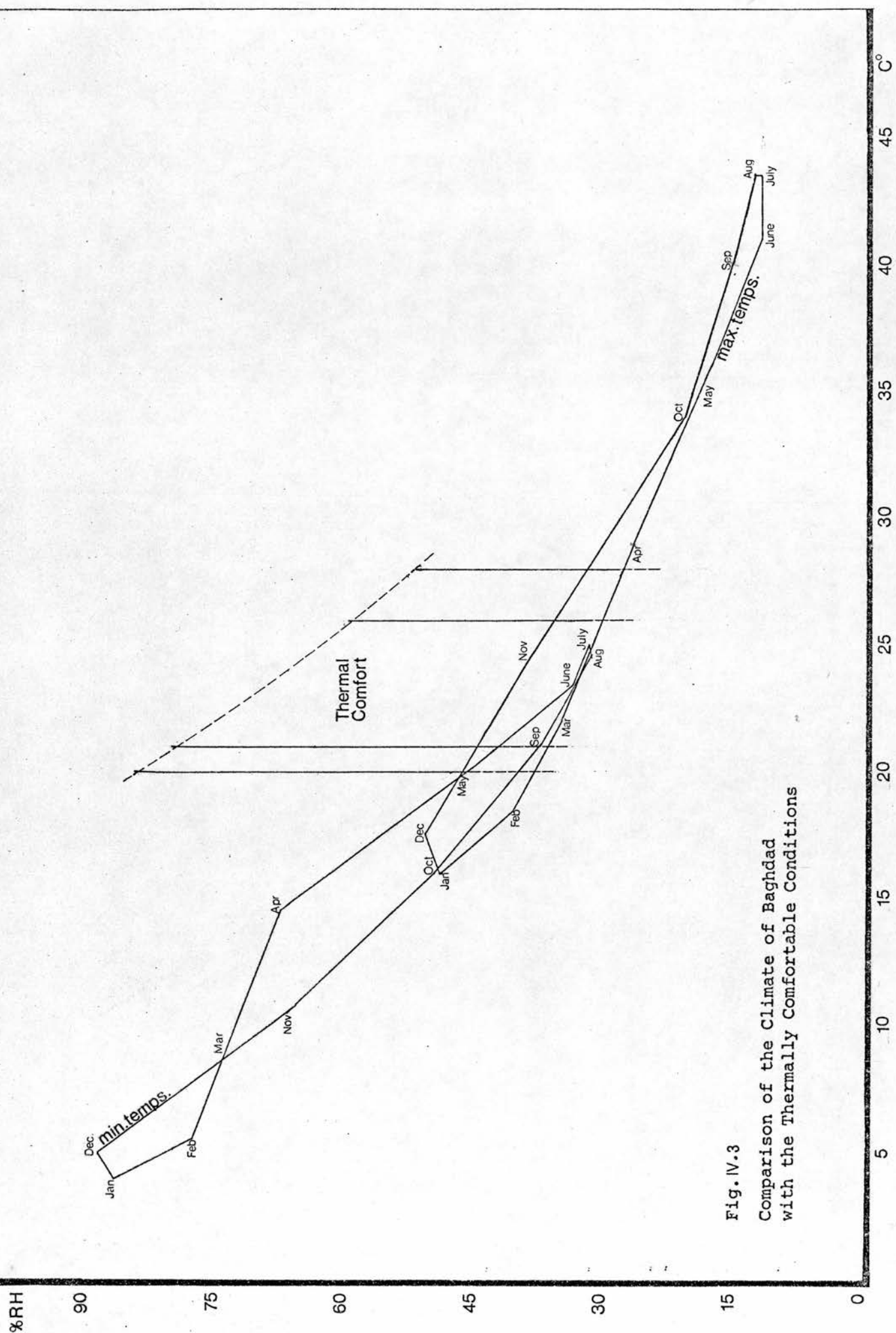


Fig. IV.3
Comparison of the Climate of Baghdad
with the Thermally Comfortable Conditions

conditions are between 5 and 17 mmHg vapour pressure with the minimum temperatures being 12 - 15°C and the maximum varying between 33°C at 17 mmHg and 39°C at 5 mmHg. It can be seen from Fig. IV.2, that readily comfortable air temperatures only exist during a small part of the year, mainly few of the day hours of November and March/April and the hours preceding sunrise in the summer season, making natural ventilation possible. These short periods can be further extended by the introduction of air movement, forced or natural, of up to 1 m/sec.

As a conclusion to the above discussion, and by reference to the Building Bioclimatic Chart of Givoni (1969) and the comfort diagram in Fig. IV.1, two charts are plotted. The Complementary Thermal Requirements Chart in Fig. IV.4 predicts periods where heating or cooling, whether evaporative or otherwise, are needed. It can be seen from this chart that heating is generally a winter night time requirement, and cooling a summer daytime one. This corresponds heating to night time use spaces like bedrooms, and cooling to daytime use spaces like living rooms. The Natural Ventilation Chart, on the other hand, Fig. IV.5, defines the times of the year of possible natural ventilation and those where an air movement, natural or induced, can act as a corrective measure.

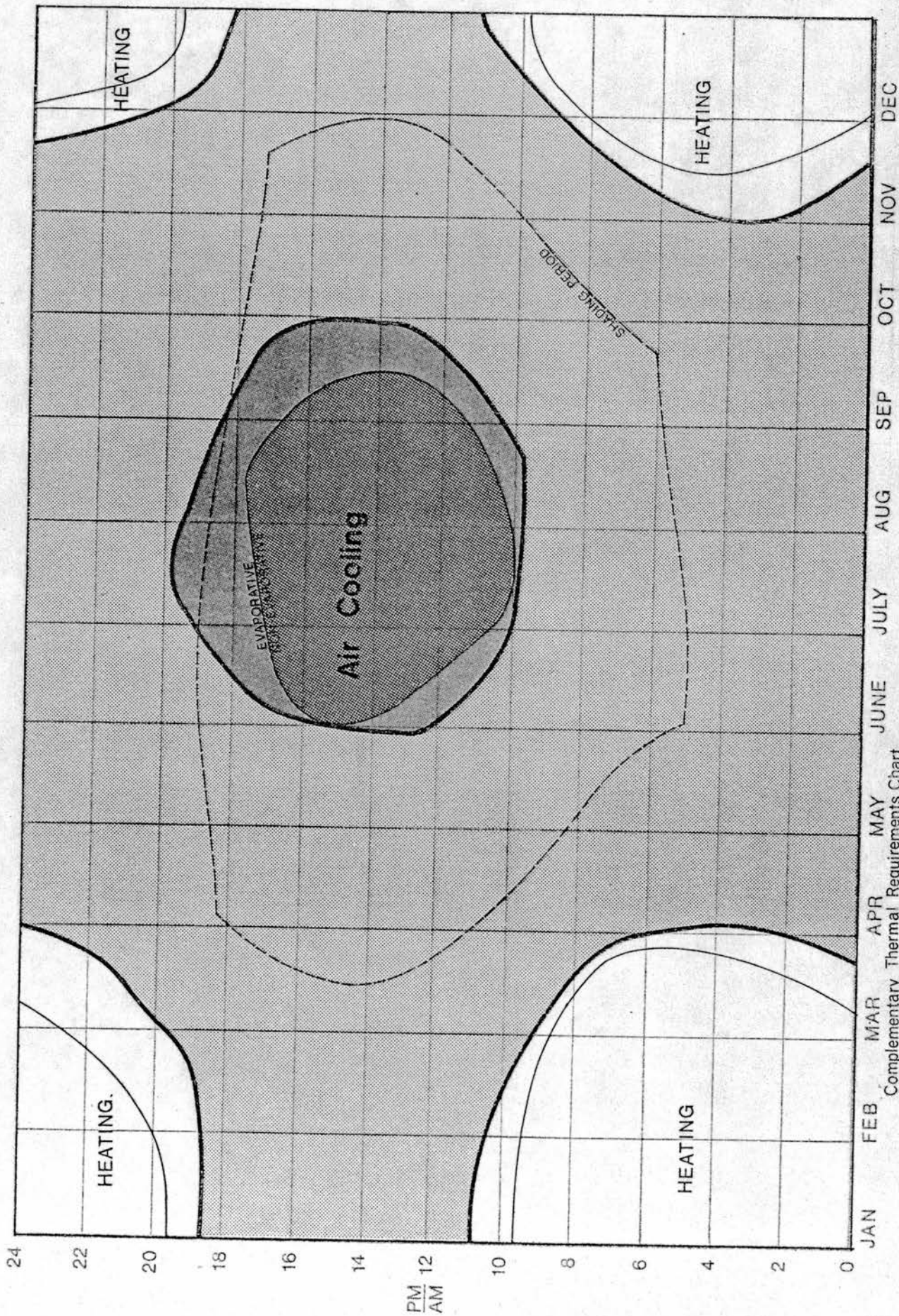


Fig.IV.4 Complementary Thermal Requirements Chart Predicted Comfortable, Hot, and Cold Parts of the Year in a Well Thermally Designed Building. The Diagram also shows Hours of Needed Shading

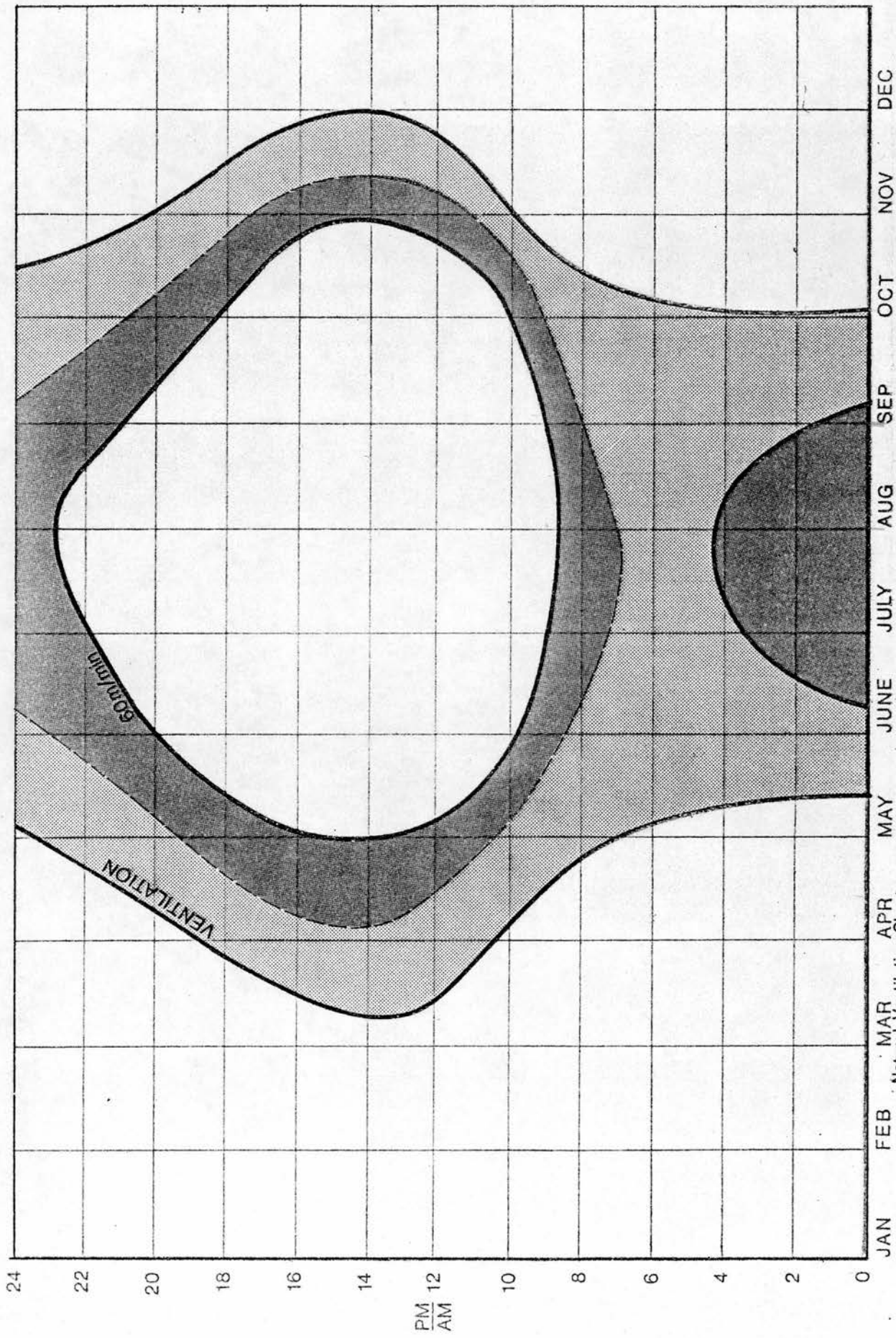


Fig. IV.5 Predicted Periods of Allowable Natural Ventilation

CHAPTER V

THE GENERATION OF THE GEOMETRY OF THE BUILDING

1. The Computer Model

The previous development of the Insolation and R and C Value indices was based on the mathematical computation of these as related to the element described by its geometrical properties. The "Insolation Table" went one step further by enabling the designer to find the insolation number for the whole geometrical form. The approach can be described as an evaluative process stemming from a comparative principle. The value of any decision made by using the table is very dependent on the number of trials attempted and the range of geometrical forms studied. These latter factors are ultimately governed by time limitations and human factors.

In this chapter we have a presentation of a descriptive outline of a computer model, using basic information relating to single elements described by their geometrical characteristics. Values for each of the assembled forms in a progression are found and the optimum form is described.

1.1 Logic and Tasks of the Model

To explain its mathematical and technical logic, the model can basically be divided into four major interlinked areas of different tasks as described below :

1.1.1 TASK ONE is the reading, organization and selection of data. The model uses numerical data on defined geometrical characteristics, namely the orientation and inclination, relating to the unit area. In this case three sets are used, I, R and C values, covering all orientations at 15° intervals e.g. N, N. 15° E, N. 30° E, and inclinations of 0° , 15° , 30° 90° i.e. horizontal to vertical; thus a set contains 168 values.

Each set of data is organized into a two-dimensional array of seven columns headed by the inclination (Col. No.) and twenty four rows headed by the orientation numbers (Row No.). Throughout the programme, a relevant data value can be recalled by using the inclination and orientation numbers of the element in question.

1.1.2 TASK TWO The model deals with one major progression, from which five other minor ones spring. The

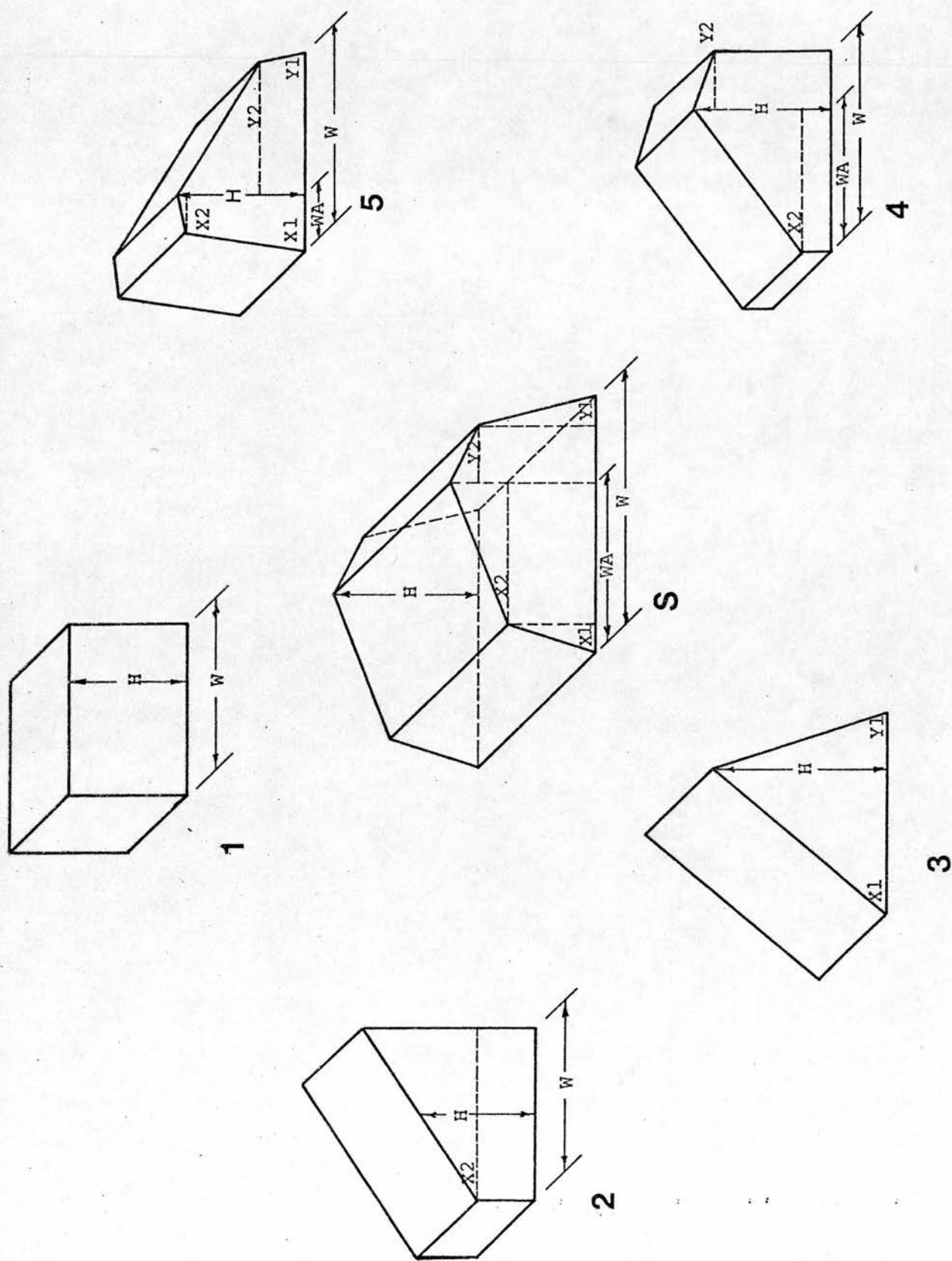


Fig.V.1 The definitive descriptors of the major progression and the five minor progressions

major progression represents the possible combinations of the variable descriptors of an axial form of a rectangular base and six elements of which the two end ones are vertical. Each two of the remaining elements have a common orientation and all their inclinations are variable (Fig. V.1). All calculations assume an equal constant volume.

The major progression has seven descriptors which can be varied independently. They are called here the definitive descriptors (DDs), of which two three or four take a constant value when forming four of the minor progressions. The fifth progression only differs from the major progression by having smaller ranges of variation of some of its DDs and satisfying the equation of progressions:

$$M = 1 + 2 + 3 + 4 + 5$$

Table V.1 shows the DDs for each progression and the assumed values for the remaining descriptors :




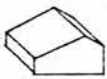

Progression		X1	X2	Y1	Y2	H	W	WA	Descriptor
M		DD	DD	DD	DD	DD	DD	DD	
 1		90	O	90	O	DD	DD		
 2		90	DD	90		DD	DD	W	
 3		DD	X1	DD	Y1	DD			
 4		90	DD	90	DD	DD	DD	DD	
 5		DD	DD	DD	DD	DD	DD	DD	

TABLE V.1

It is the number of DDs and the size of their ranges of variation that determine the size of the progression since they determine the number of possibilities. Table V.2 shows the range of each DD for each progression.




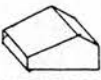
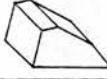
Progression	X1	X2	Y1	Y2	H	W	WA	Descriptor
M	15-90	O-X1 X2 \neq 90	15-90	O-Y1 Y2 \neq 90	1-10	1-10	O-W	
 1					1-10	1-10		
 2		15 ⁺ 75			1-10	1-10		
 3	15-90		15-90		1-10			
 4		O-75		O-75	1-10	2-10	1-(W-1)	
 5	15-75	15-75	15-75	15-75	1-10	1-10	O-W	

TABLE V.2

The aim here is to use every possible combination of DDs in the major progression in assembling a geometrical form, the calculation of the elemental areas of which will be the next step.

The model also includes a few check points to prove the acceptability of the geometry produced. This is done here by applying limits within which a form can be considered architecturally favourable. As an example to this we take the dimension of the depth in relation to the other descriptors

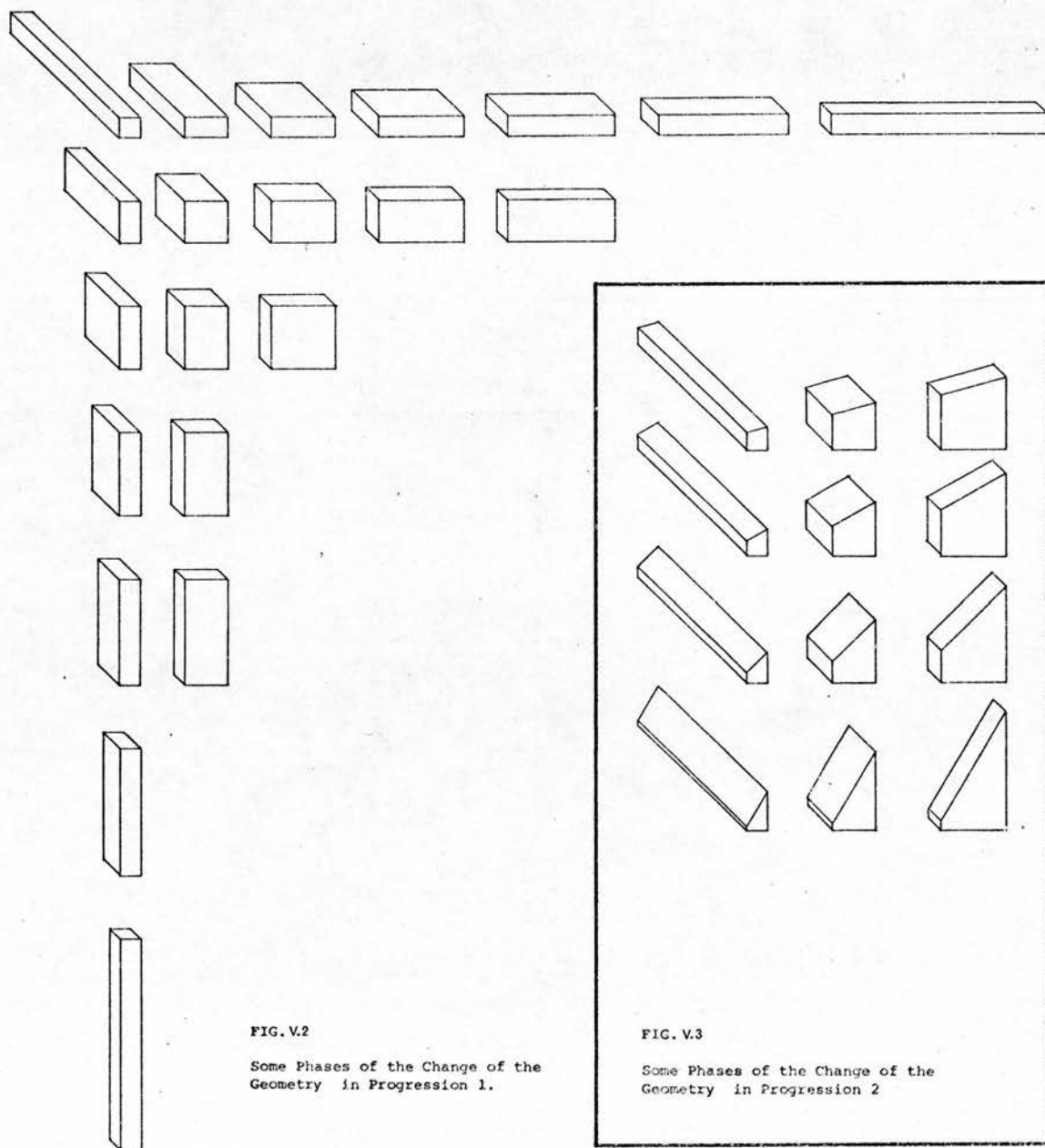


FIG. V.2

Some Phases of the Change of the
Geometry in Progression 1.

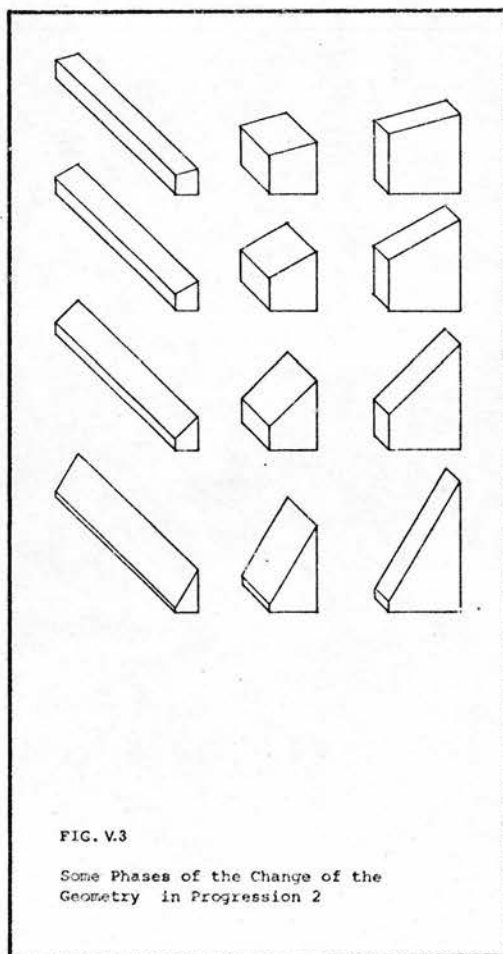


FIG. V.3

Some Phases of the Change of the
Geometry in Progression 2

of the form. Assuming a volume of 10, the following limitation is applied :

$$1 \leq \text{Depth} \leq 10$$

1.1.3 TASK THREE This is the final operational part of the model. It uses in its calculations the results obtained from the previous parts. The objective here is to find all the elemental values and therefore the geometrical form value which is a preliminary model goal. The first stage involves the multiplication of the area of each element, which has already been found in the last part, by the relevant data value, which can be located and recalled by using the elemental descriptors (inclination and orientation numbers). The form value is then found by summing all the elemental values.

A further task of this part is to find whether the calculated form value is the smallest of all previously calculated ones comparing it with their smallest. By this process the minimum value is found and the form is labelled optimum.

Having used three sets of values, I, R and C, the model will find three optimum forms and label them as such. An I optimum form is one which receives the least amount of over-21

solar radiation. An R or C optimum form, on the other hand, is one which yields the smallest total R or C value.

1.1.4 TASK FOUR This part of the model is a purely technical one, since it involves the output of the results obtained. The computer output of this model is in the form of numbers relating to each possible form geometry. It also includes a description of the optimum geometrical forms at each attempted orientation. Due to the large number of geometries involved, the number of values generated by the computer is one of too great a magnitude to be handled and analysed explicitly, in spite of being of interest to the researcher. A concise method of presentation is explained later in this chapter.

Tasks three and four are repeated for all orientations at 15° intervals.

1.2 The Data

As has been discussed earlier, the model uses numerical data relating to the unit area of each possible elemental plane. Taking 24 orientations and 7 inclinations considered, a data set would have to contain 168 values. Tables V.3-5 are of three sets of data put in two-dimensional arrays. These values are the results of calculations made in chapters II and III in this thesis.

INCLINATION →		90 1		75 2		60 3		45 4		30 5		15 6		0 7	
Col No.	→	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Orientation	→	1	2	3	4	5	6	7	8	9	10	11	12	13	14
N	→	1	2	3	4	5	6	7	8	9	10	11	12	13	14
15	→	1	2	3	4	5	6	7	8	9	10	11	12	13	14
30	→	1	2	3	4	5	6	7	8	9	10	11	12	13	14
45	→	1	2	3	4	5	6	7	8	9	10	11	12	13	14
60	→	1	2	3	4	5	6	7	8	9	10	11	12	13	14
75	→	1	2	3	4	5	6	7	8	9	10	11	12	13	14
E	→	1	2	3	4	5	6	7	8	9	10	11	12	13	14
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120	→	1	2	3	4	5	6	7	8	9	10	11	12	13	14
135	→	1	2	3	4	5	6	7	8	9	10	11	12	13	14
150	→	1	2	3	4	5	6	7	8	9	10	11	12	13	14
165	→	1	2	3	4	5	6	7	8	9	10	11	12	13	14
S	→	1	2	3	4	5	6	7	8	9	10	11	12	13	14
195	→	1	2	3	4	5	6	7	8	9	10	11	12	13	14
210	→	1	2	3	4	5	6	7	8	9	10	11	12	13	14
225	→	1	2	3	4	5	6	7	8	9	10	11	12	13	14
240	→	1	2	3	4	5	6	7	8	9	10	11	12	13	14
255	→	1	2	3	4	5	6	7	8	9	10	11	12	13	14
W	→	1	2	3	4	5	6	7	8	9	10	11	12	13	14
285	→	1	2	3	4	5	6	7	8	9	10	11	12	13	14
300	→	1	2	3	4	5	6	7	8	9	10	11	12	13	14
315	→	1	2	3	4	5	6	7	8	9	10	11	12	13	14
330	→	1	2	3	4	5	6	7	8	9	10	11	12	13	14
345	→	1	2	3	4	5	6	7	8	9	10	11	12	13	14

JOB-STEP RETURN CODE= 0

TABLE (V.3) I Values (J.m⁻².year⁻¹)

INCLINATION → 90		75		60		45		30		15		0	
Col No.	1	2	3	4	5	6	7	8	9	10	11	12	13
Row No.	1	2	3	4	5	6	7	8	9	10	11	12	13
N	8.141097E-01	9.115735E-01	9.904045E-01	1.046303E 00	1.248397E 00	1.447624E 00	1.613886E 00	1.748615E 00					
15	8.872076E-01	9.904045E-01	1.089301E 00	1.281363E 00	1.454791E 00	1.613886E 00	1.748615E 00						
30	1.025033E 00	1.119400E 00	1.226897E 00	1.351594E 00	1.489190E 00	1.621053E 00	1.748615E 00						
45	1.113667E 00	1.208264E 00	1.305872E 00	1.423258E 00	1.536489E 00	1.628219E 00	1.748615E 00						
60	1.165266E 00	1.264163E 00	1.371659E 00	1.474856E 00	1.563721E 00	1.643985E 00	1.748615E 00						
75	1.206831E 00	1.314328E 00	1.426125E 00	1.519289E 00	1.592386E 00	1.665484E 00	1.748615E 00						
E	1.232631E 00	1.347294E 00	1.461957E 00	1.545088E 00	1.612453E 00	1.679817E 00	1.748615E 00						
105	1.252696E 00	1.381693E 00	1.486323E 00	1.578053E 00	1.639686E 00	1.694150E 00	1.748615E 00						
120	1.274196E 00	1.403193E 00	1.510689E 00	1.596686E 00	1.654018E 00	1.701317E 00	1.748615E 00						
135	1.284229E 00	1.414659E 00	1.513556E 00	1.616753E 00	1.666918E 00	1.717083E 00	1.748615E 00						
150	1.294262E 00	1.426125E 00	1.540788E 00	1.629652E 00	1.681251E 00	1.724250E 00	1.748615E 00						
165	1.299995E 00	1.431858E 00	1.546521E 00	1.635386E 00	1.688417E 00	1.731416E 00	1.748615E 00						
S	1.294262E 00	1.431858E 00	1.552255E 00	1.642551E 00	1.695583E 00	1.74250E 00	1.748615E 00						
195	1.299995E 00	1.431858E 00	1.546521E 00	1.635386E 00	1.688417E 00	1.731416E 00	1.748615E 00						
210	1.294262E 00	1.426125E 00	1.540788E 00	1.629652E 00	1.681251E 00	1.724250E 00	1.748615E 00						
225	1.284229E 00	1.414659E 00	1.527888E 00	1.616753E 00	1.666918E 00	1.717083E 00	1.748615E 00						
240	1.274196E 00	1.403193E 00	1.510689E 00	1.596686E 00	1.654018E 00	1.701317E 00	1.748615E 00						
255	1.252696E 00	1.381693E 00	1.486323E 00	1.578053E 00	1.639686E 00	1.694150E 00	1.748615E 00						
W	1.232631E 00	1.347294E 00	1.461957E 00	1.545088E 00	1.612453E 00	1.679817E 00	1.748615E 00						
285	1.206831E 00	1.314328E 00	1.426125E 00	1.519289E 00	1.592386E 00	1.665484E 00	1.748615E 00						
300	1.165266E 00	1.264163E 00	1.371659E 00	1.474856E 00	1.563721E 00	1.643985E 00	1.748615E 00						
315	1.113667E 00	1.208264E 00	1.305872E 00	1.423258E 00	1.536489E 00	1.628219E 00	1.748615E 00						
330	1.025033E 00	1.119400E 00	1.226897E 00	1.351594E 00	1.489190E 00	1.621053E 00	1.748615E 00						
345	8.872076E-01	9.904045E-01	1.089301E 00	1.281363E 00	1.454791E 00	1.613886E 00	1.748615E 00						

JOB-STEP RETURN CODE= 0

TABLE (V.4) R Values (m²C.W⁻¹)

INCLINATION →		90		75		60		45		30		15		0	
Col No.	→	1	2	3	4	5	6	7	8	9	10	11	12	13	14
N		1	2	3	4	5	6	7	8	9	10	11	12	13	14
15		2	3	4	5	6	7	8	9	10	11	12	13	14	15
30		2	3	4	5	6	7	8	9	10	11	12	13	14	15
45		2	3	4	5	6	7	8	9	10	11	12	13	14	15
60		2	3	4	5	6	7	8	9	10	11	12	13	14	15
75		2	3	4	5	6	7	8	9	10	11	12	13	14	15
E		2	3	4	5	6	7	8	9	10	11	12	13	14	15
105		2	3	4	5	6	7	8	9	10	11	12	13	14	15
120		2	3	4	5	6	7	8	9	10	11	12	13	14	15
135		2	3	4	5	6	7	8	9	10	11	12	13	14	15
150		2	3	4	5	6	7	8	9	10	11	12	13	14	15
165		2	3	4	5	6	7	8	9	10	11	12	13	14	15
S		2	3	4	5	6	7	8	9	10	11	12	13	14	15
195		2	3	4	5	6	7	8	9	10	11	12	13	14	15
210		2	3	4	5	6	7	8	9	10	11	12	13	14	15
225		2	3	4	5	6	7	8	9	10	11	12	13	14	15
240		2	3	4	5	6	7	8	9	10	11	12	13	14	15
255		2	3	4	5	6	7	8	9	10	11	12	13	14	15
W		2	3	4	5	6	7	8	9	10	11	12	13	14	15
285		2	3	4	5	6	7	8	9	10	11	12	13	14	15
300		2	3	4	5	6	7	8	9	10	11	12	13	14	15
315		2	3	4	5	6	7	8	9	10	11	12	13	14	15
330		2	3	4	5	6	7	8	9	10	11	12	13	14	15
345		2	3	4	5	6	7	8	9	10	11	12	13	14	15

008-STEP RETURN CODE= 0

TABLE (V.5) C VALUES (J.m⁻².°C)

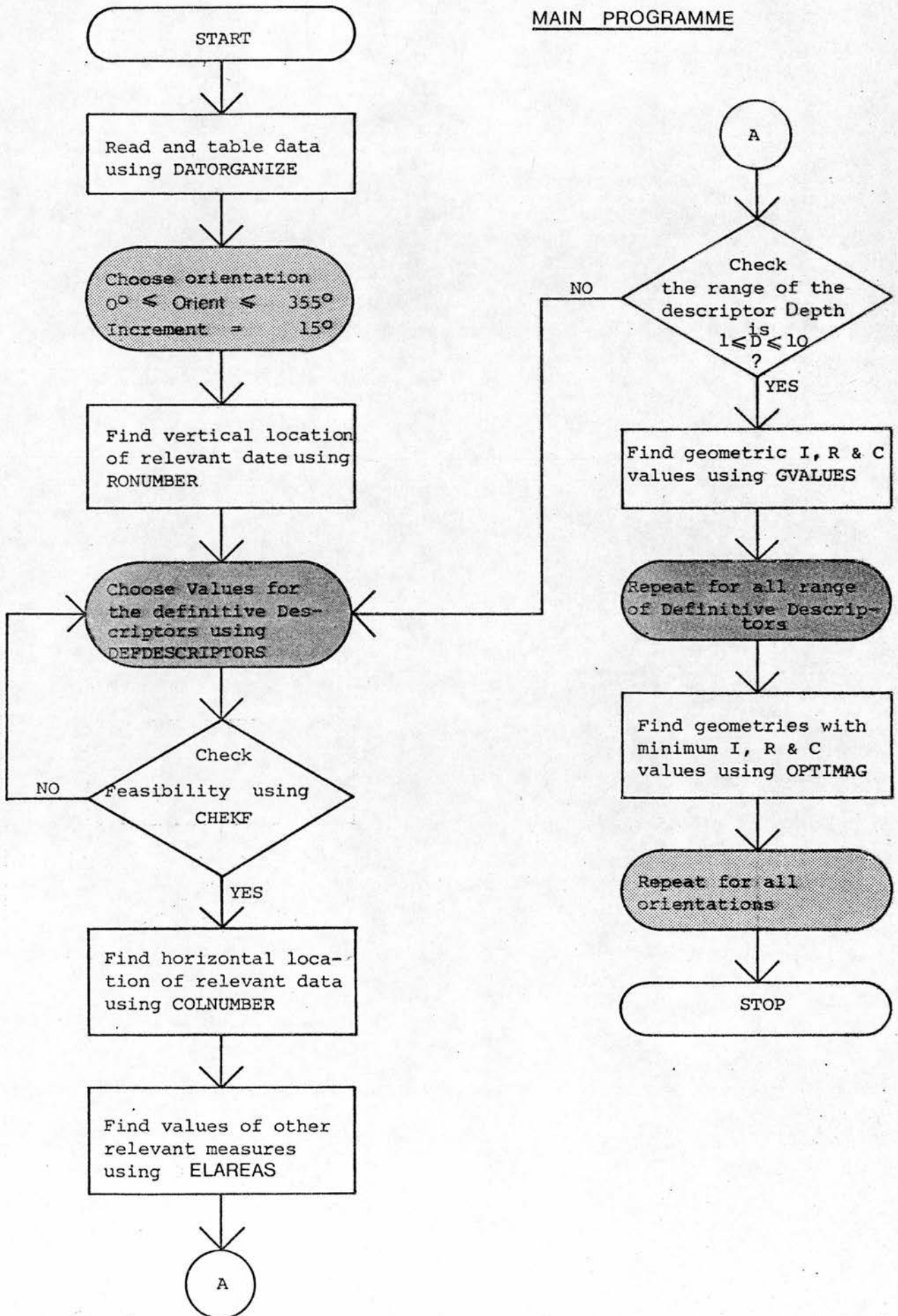
1.3 The Flow Charts

Although flow charts are usually determined by the individual's way of thinking, they are considered here as the best possible media for explaining the technical aspect of the model, since a final computer programme can be ambiguous and cumbersome to understand for reasons such as inborn characteristics pertaining to the programming language.

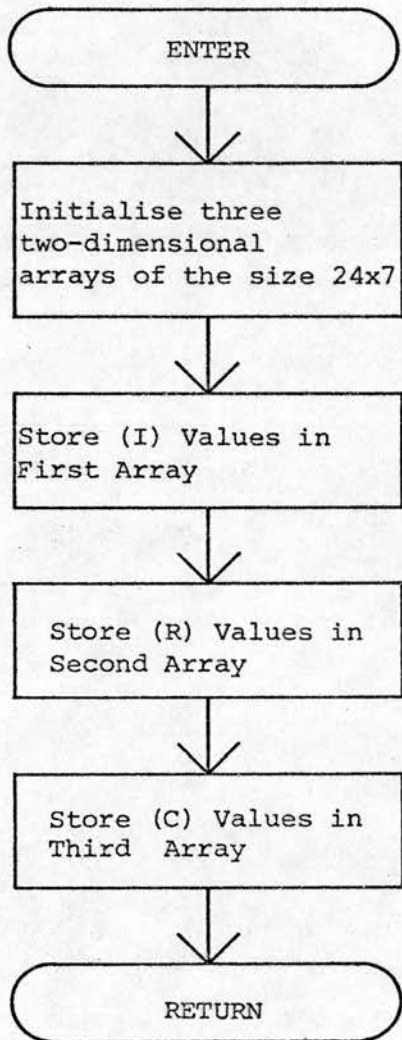
The shapes used in the flow charts have different significances. Other than signifying the beginning or end of a programme or sub-programme, an ellipse can indicate the start or end of a cycle. To eliminate ambiguity in this matter, each two ellipses of one cycle are given a different shade. Rectangular shapes are used for straightforward instructions such as mathematical calculations and the reading of data. For testing operations diamonds are used; a diamond always has two outlets, one to be followed when the result of the test is positive and it is labelled YES, and the other when the result is negative and it is labelled NO.

A small circle containing a capital letter indicates that the chart continues elsewhere due to lack of space. The remaining part of the chart starts with a matching circle. Sub-programmes are referred to by their names which are written in capitals.

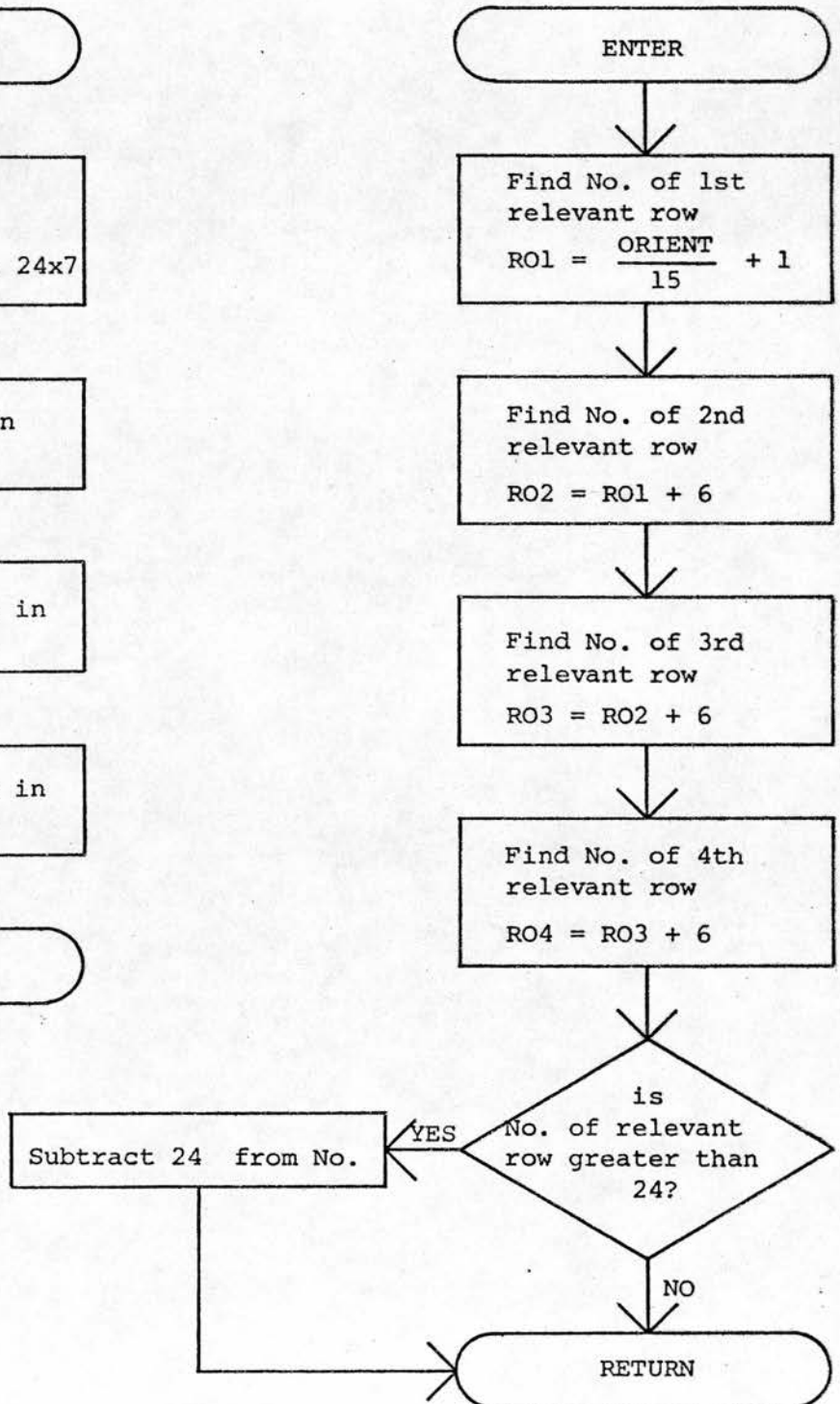
MAIN PROGRAMME



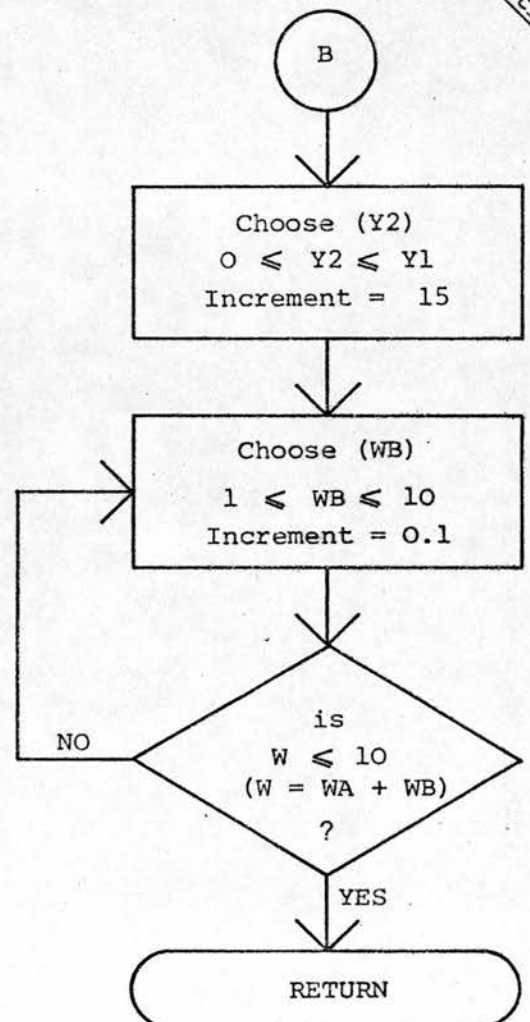
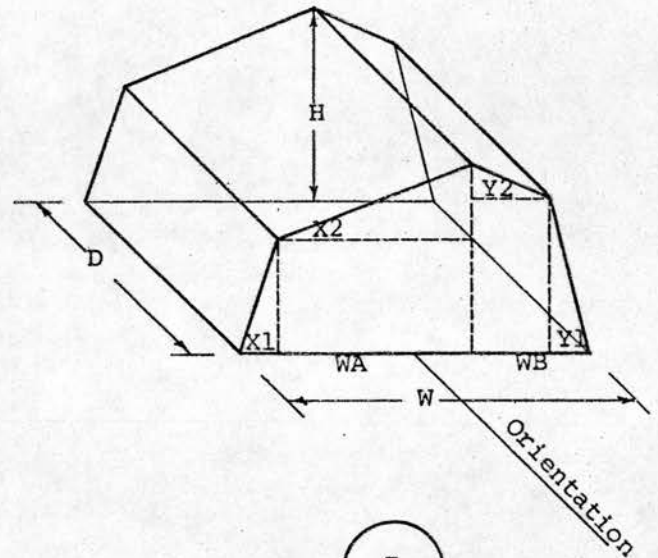
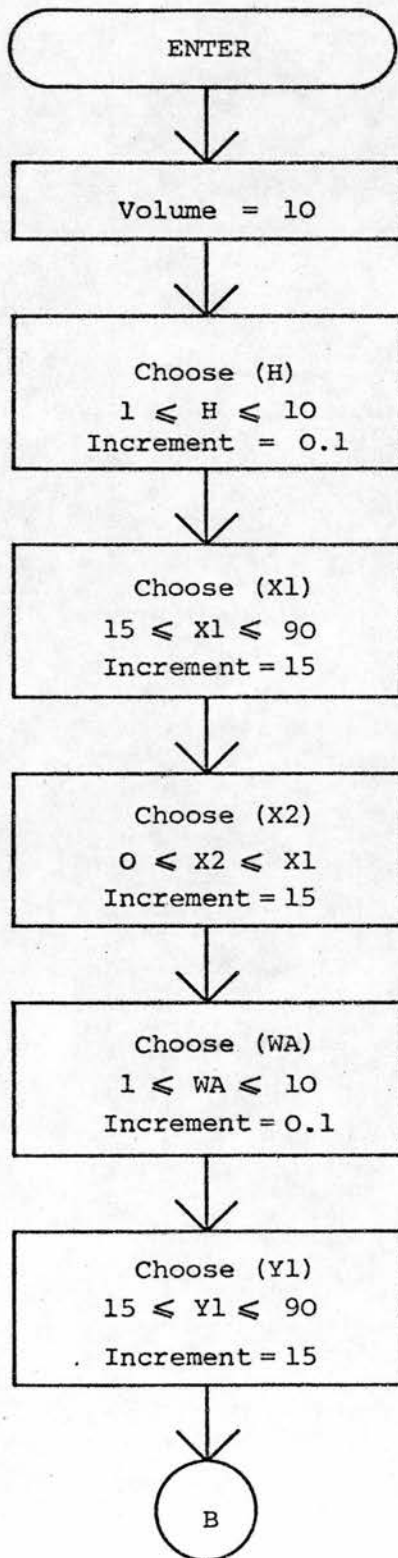
DATORGANIZE



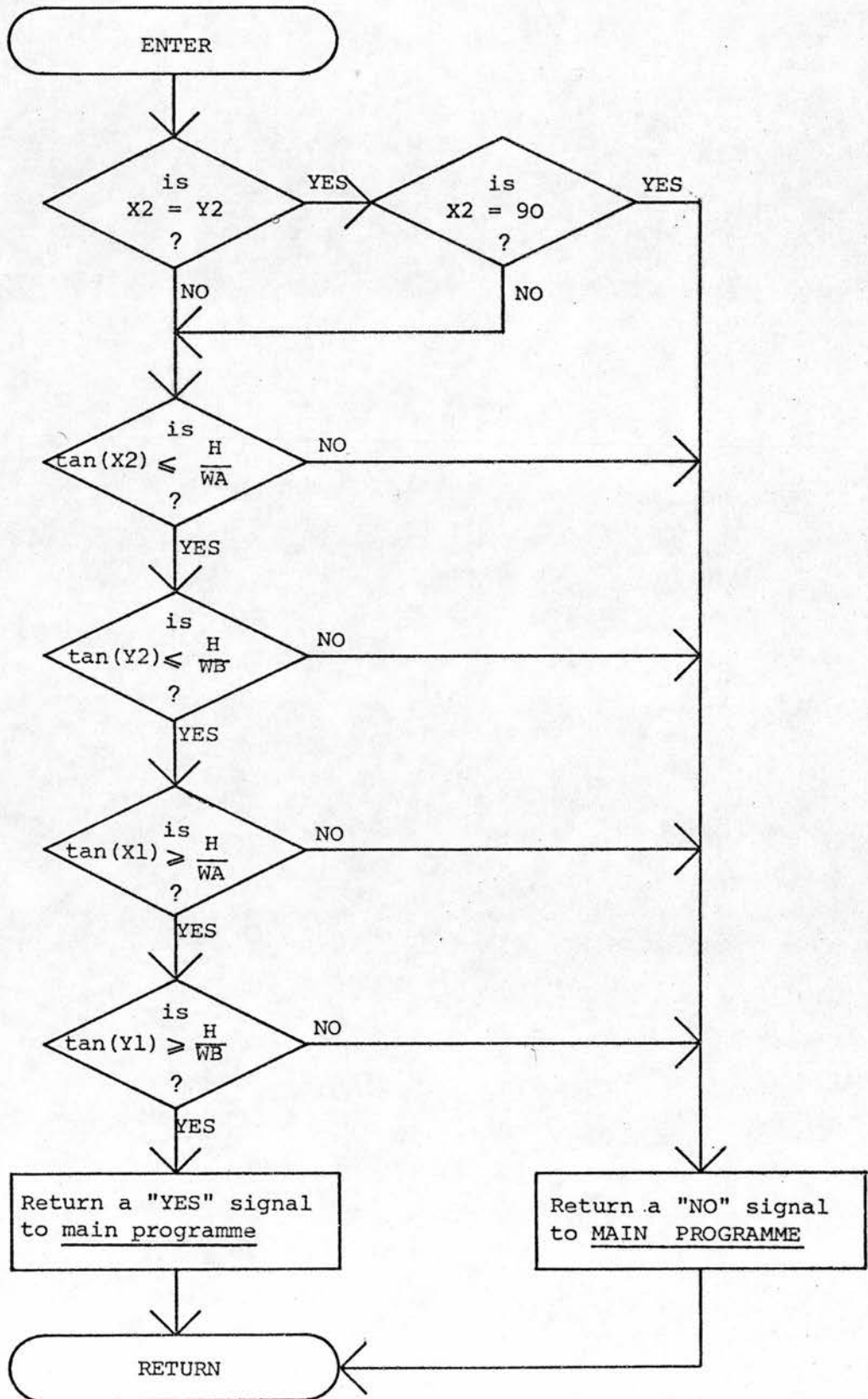
RONUMBER



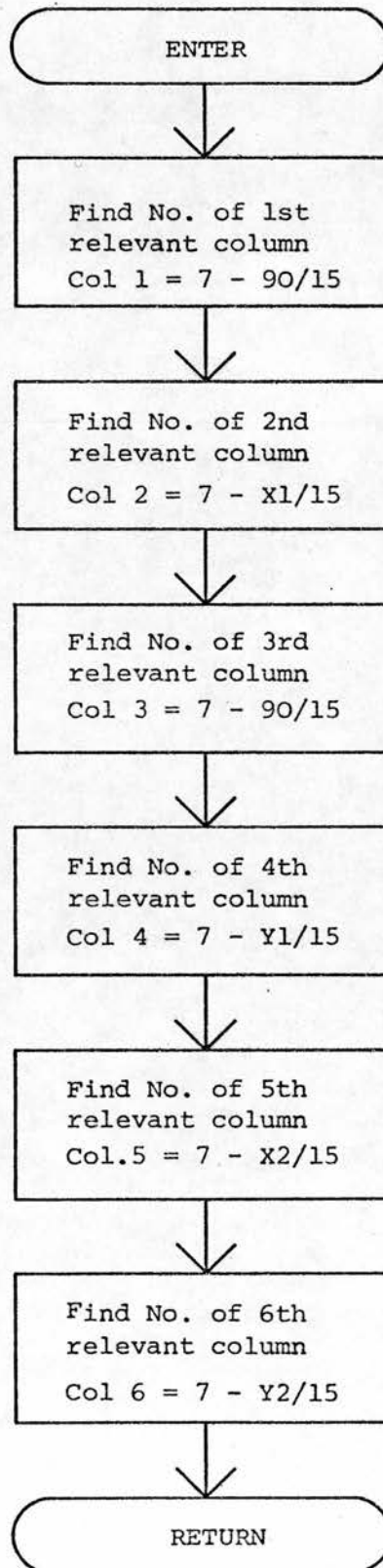
DEF DESCRIPTORS

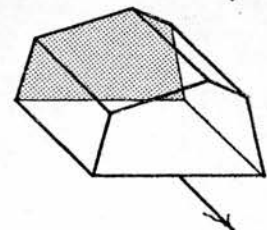
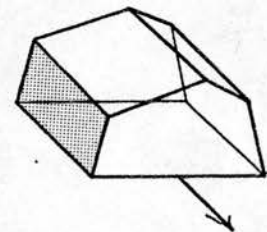
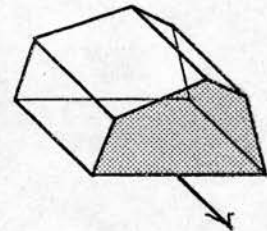
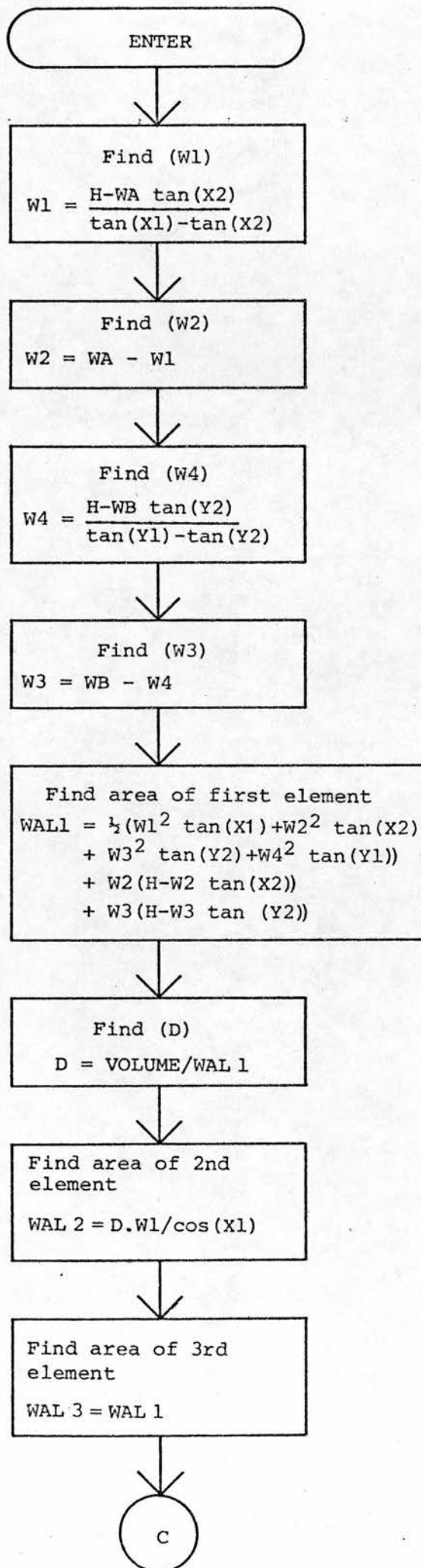


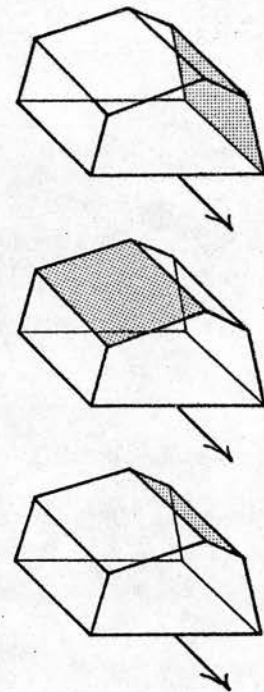
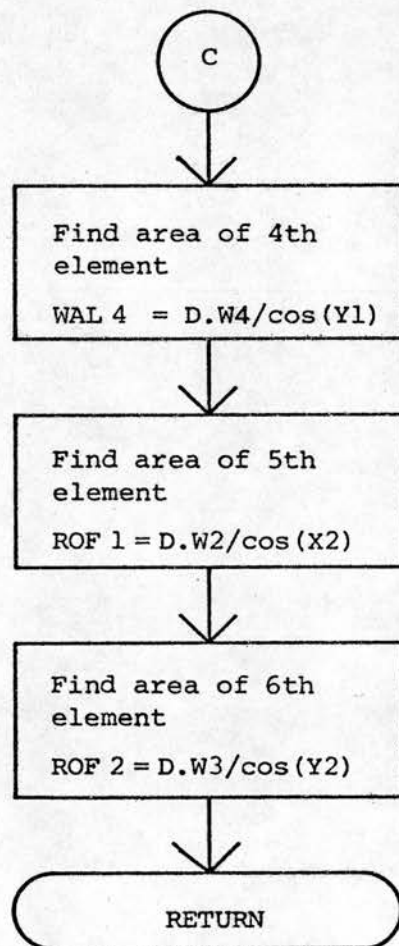
CHEKF



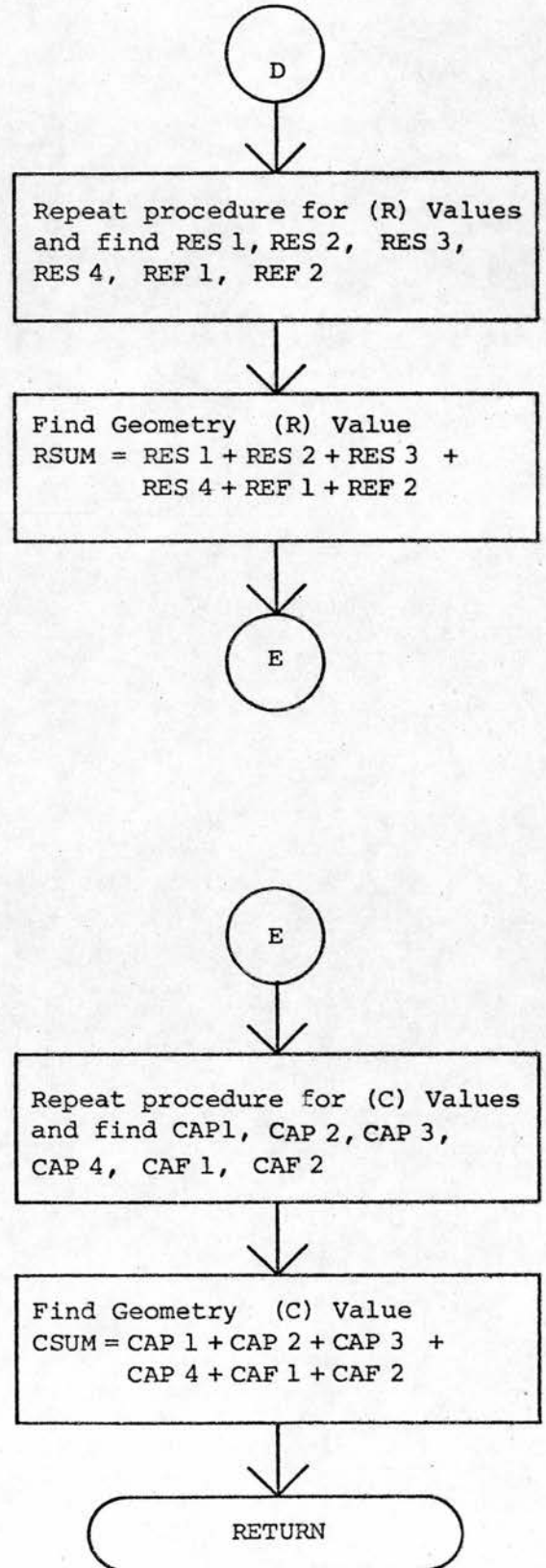
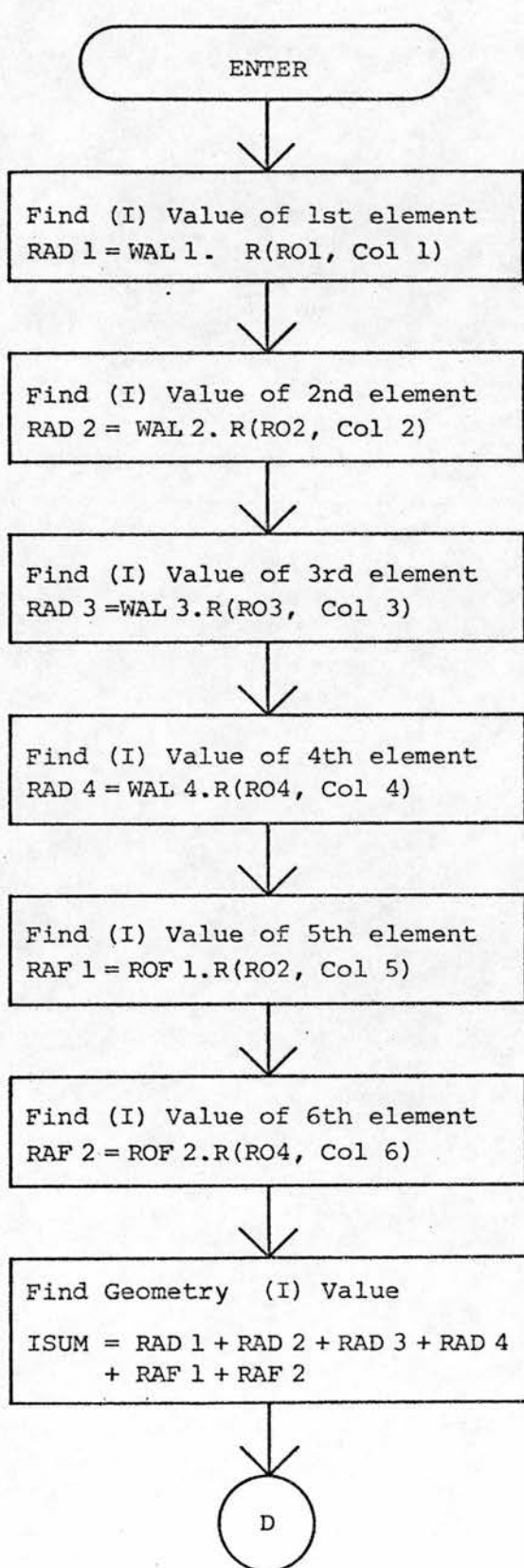
COLNUMBER

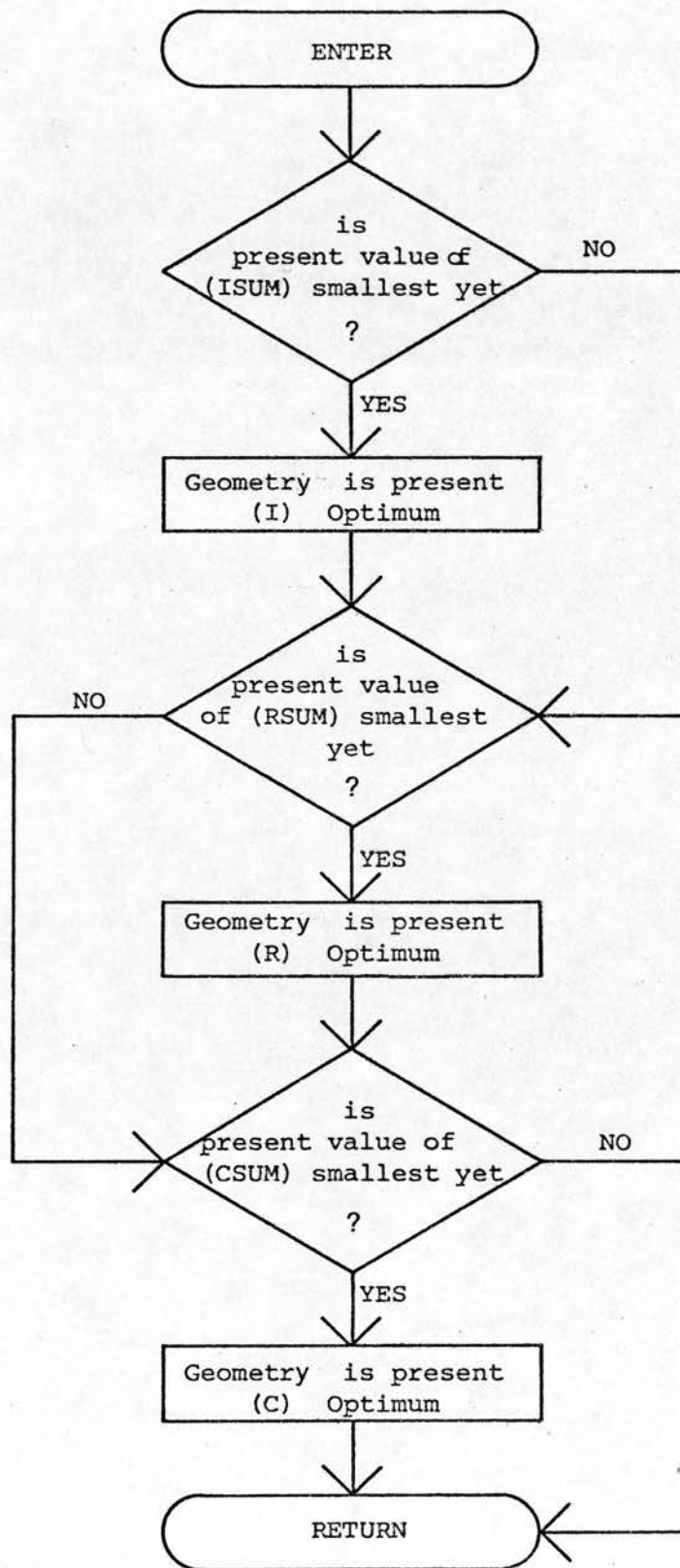






GVALUES





1.4 The Results

1.4.1 Presentation Format - The "Optimum Progression" Concept

Owing to the sizes of the progressions involved, the size of decrement chosen in the values of the descriptors, and the basic mathematical logic of the model, a great amount of intermediate results are obtained during the operation. These results are in the form of a very large number of figures representing I, R and C values for every possible geometrical form in the major progression. To overcome the presentational problem caused by this, the concept of the optimum progression is used.

The optimum progression is a set of twenty four form geometries of one minor progression, each being the corresponding optimum form for a particular orientation (e.g. N, N.15[°].E, N.30[°].E). It can also be defined as being the changes through which a form geometry has to pass to remain optimum when rotated in steps through 360[°]. It is on this definition the analysis and discussion will later be based.

The R and C optima progressions for the five minor progressions studied by the model are presented in Figs. V.6-10 as one set of progressions because they have coincidental patterns. This

is due to the fact that the R and C data vary similarly throughout their arrays.

1.4.2 The Progressional I, R and C-Value Curves

These are two diagrams each containing a set of five curves, I-value curves or RC-value curves (Fig. V.11). Each curve belongs to one optimum progression and represents the change in the form I-value or RC-value throughout the progression. The vertical scales indicate I, R and C values. The orientational axes are marked vertically across the diagram. An orientational axis is the line pointing to two opposite geographical directions (e.g. N/S, E/W), and with which the form's axis coincides at one step of the progression.

The I-Optima progressions and the Progressional I-Value Curves are later incorporated in the generative model in chapter VI, pages VI.5-10. To avoid repetition, these graphs are not included in this chapter.

1.4.3 Results Presentation Format

The format of the presentation is that of simple graph having two axes. The vertical axis on the left is a value scale for the linear descriptors; the horizontal being an orientation scale. When angular descriptors are involved, an angular

scale is used on the right hand side of the graph. Fig. V.4 shows a key of presentation of each of the descriptors.











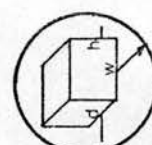
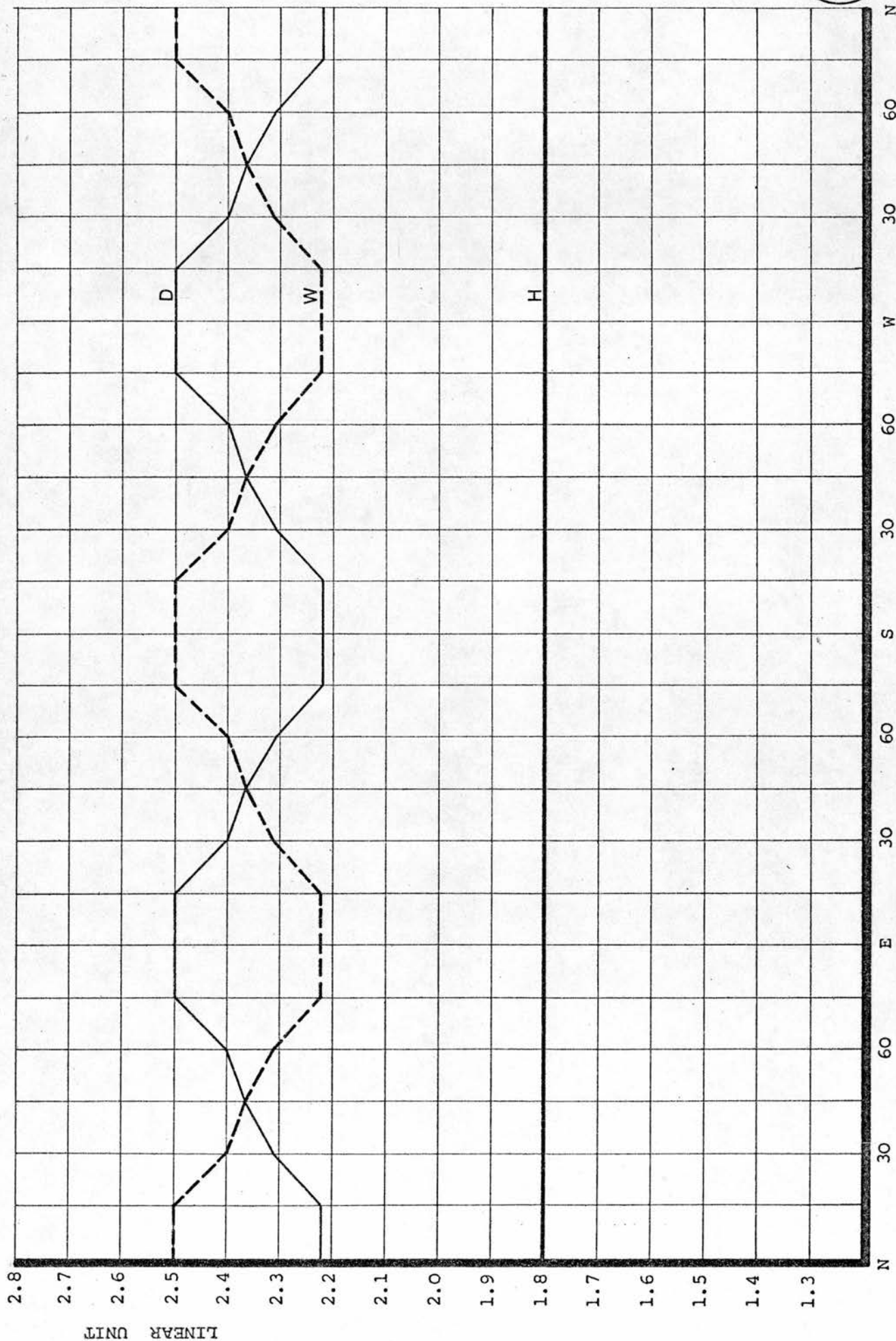
Linear Descriptors		H (Height)
		W (Width)
		WA
		D (Depth)
Angular Descriptors		X1
		X2
		-X2
		Y1
		Y2
		

Fig. V.4 Key to descriptor presentation in the optima progressions



RC-OPT.P.1

FIG. V.5 The behavioural Pattern of the Descriptors in RC-OPTIMUM Progression 1

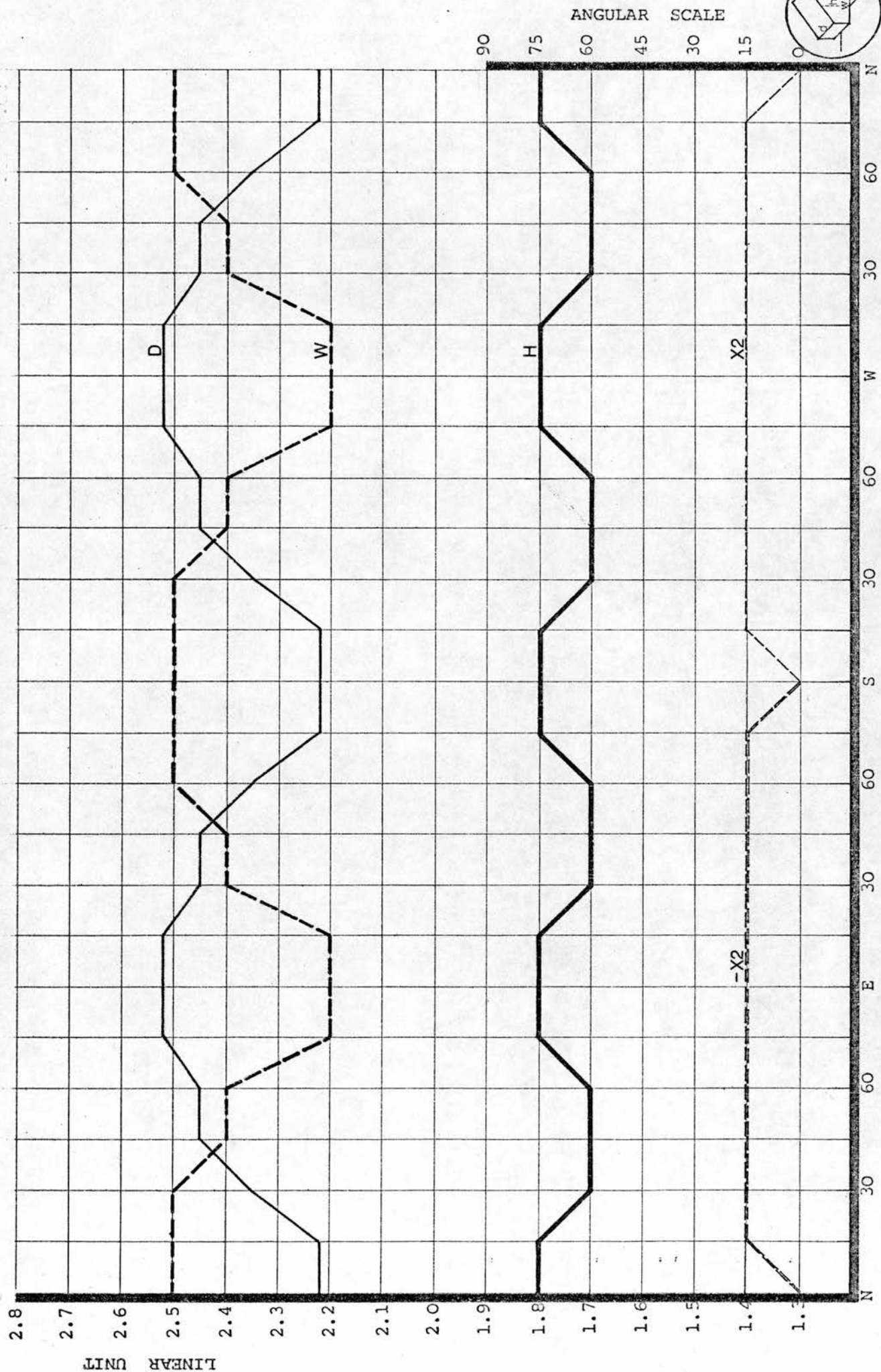


FIG.V.6 The Behavioural Pattern of the Descriptors in RC-OPTIMUM Progression 2

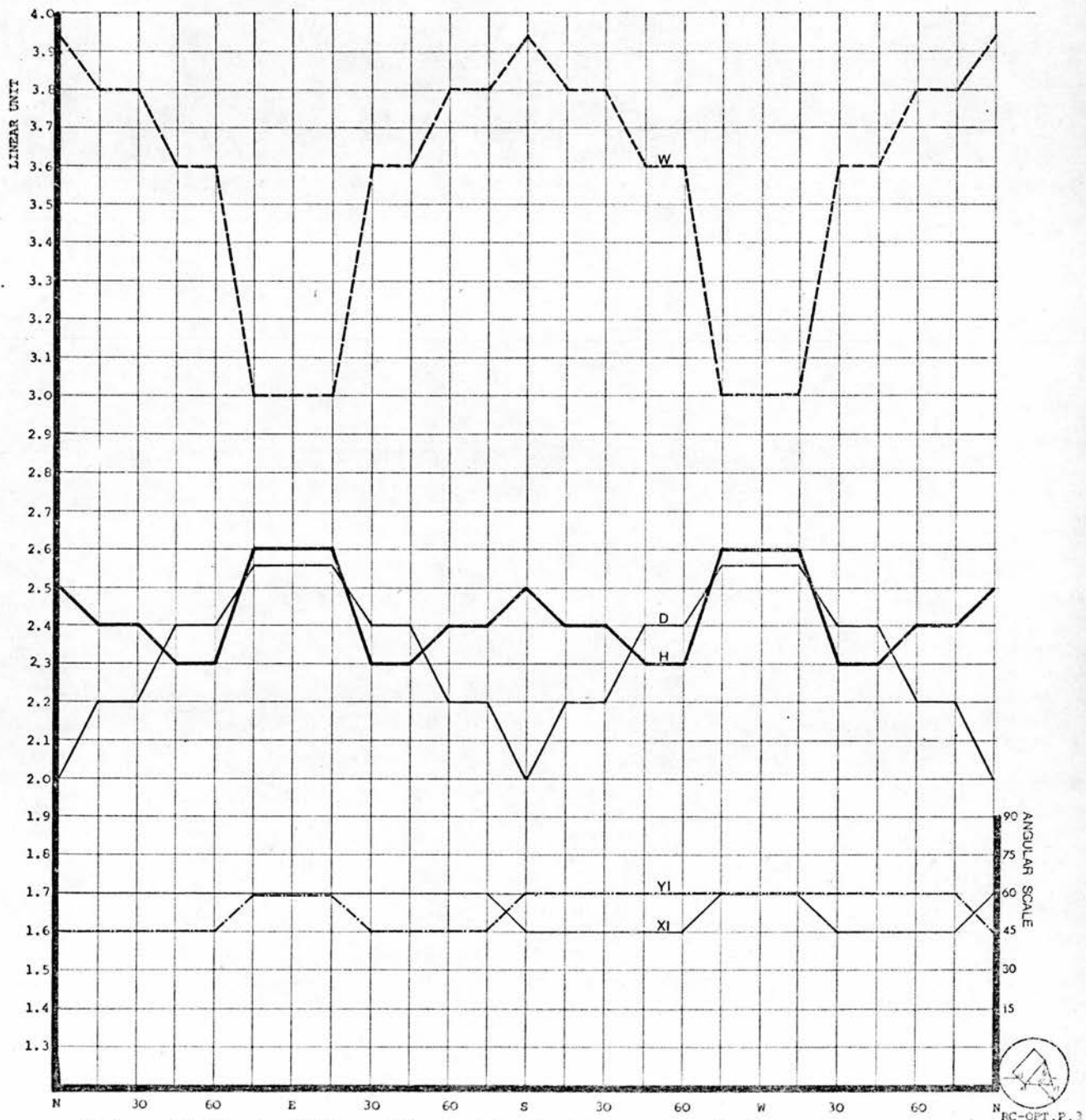


FIG. V.7 The Behavioural Pattern of the Descriptors in RC-Optimum Progression 3



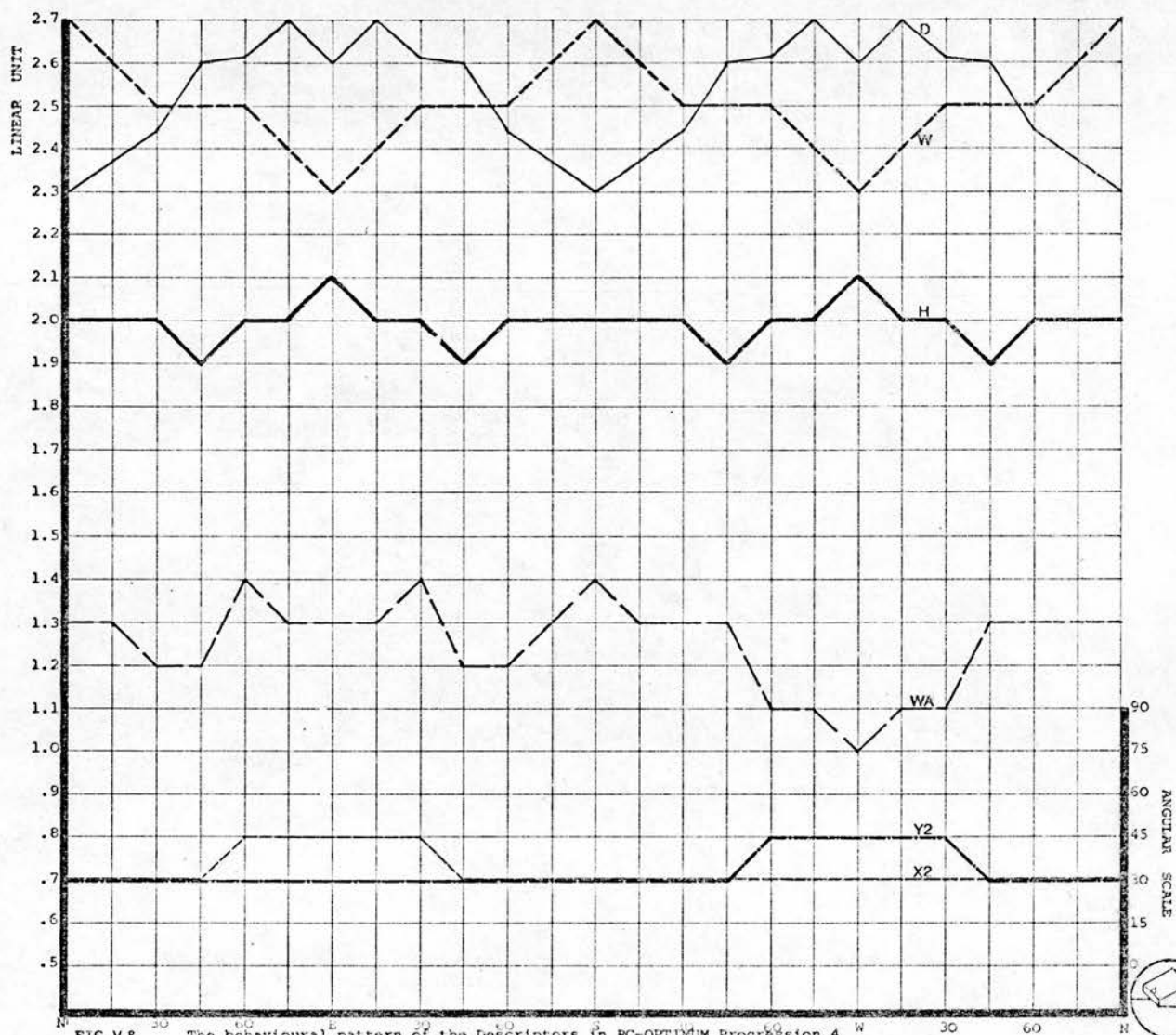


FIG.V.8 The behavioural pattern of the Descriptors in RC-OPTIMUM Progression 4

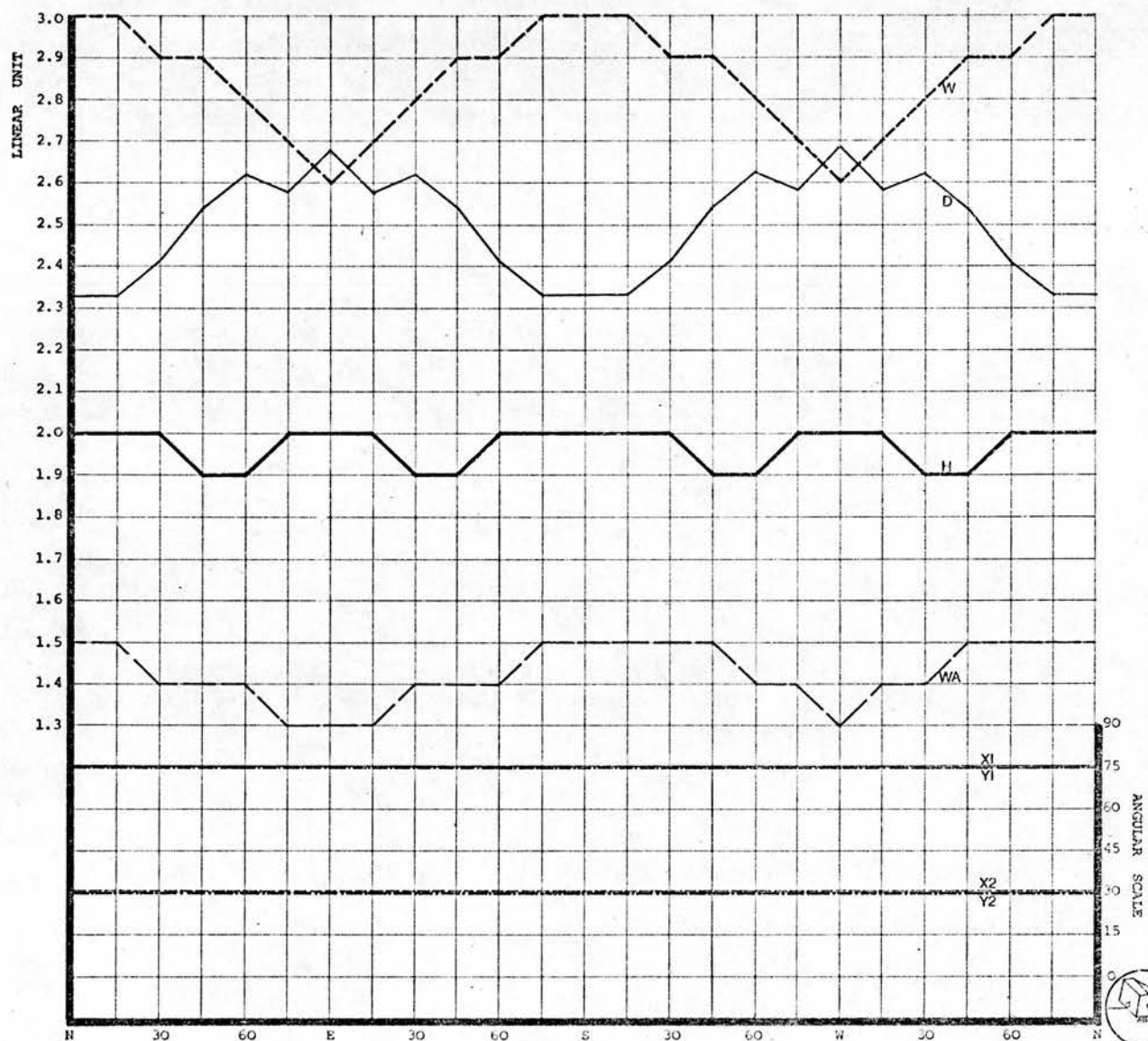
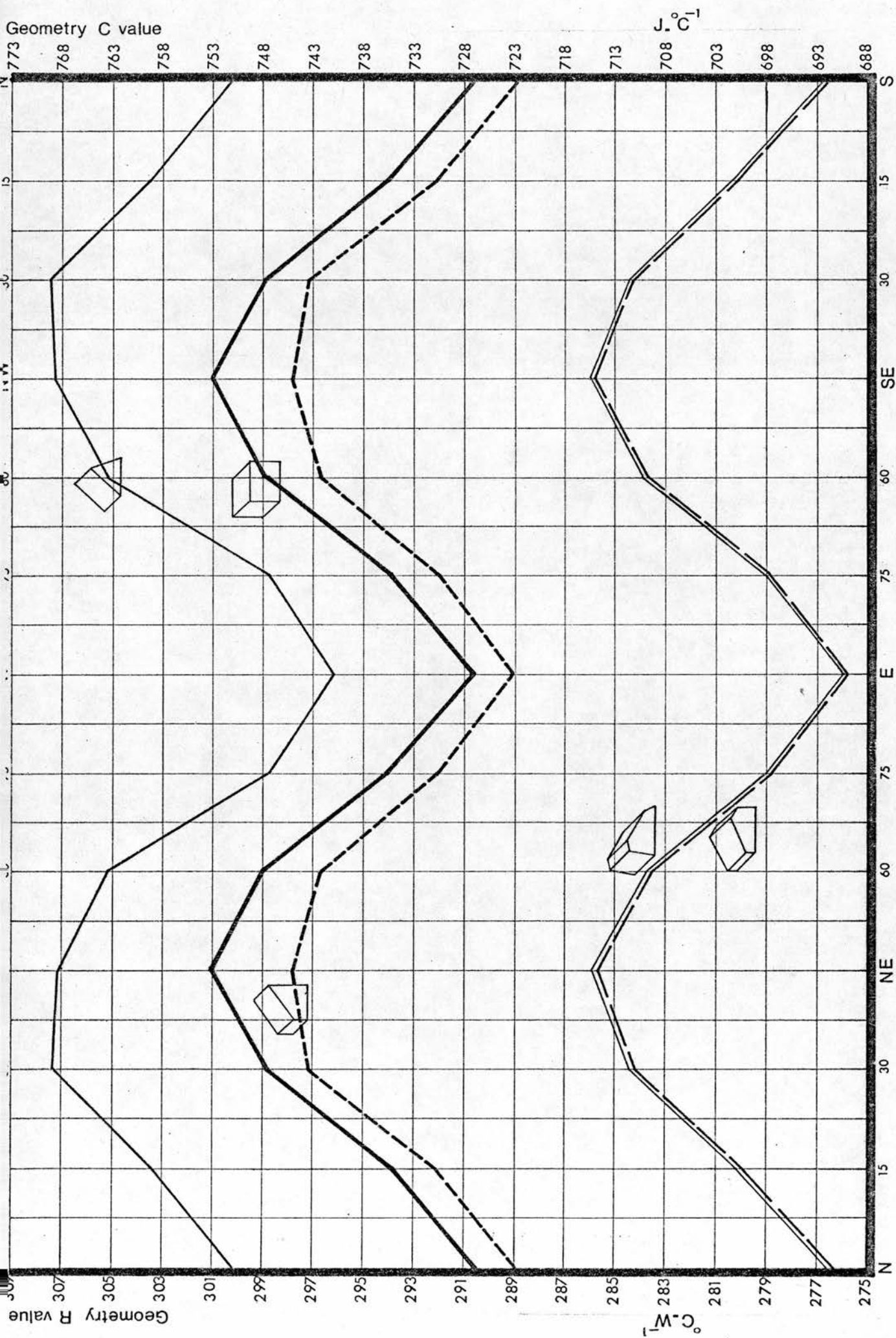


FIG. V.9 The Behavioural Pattern of the Descriptors in RC-OPTIMUM Progression 5



1.5 Study and Analysis of the Results

1.5.1 I-Optima Progressions (I-OPT.P.) (See pages VI.5-10 of next chapter)

The analysis and study of the results are carried out here by studying the general pattern of the graph of each I-Optimum progression, the change in each descriptor value with orientation, and a general comparison between individual progressions. Since the forms used are tubular varying in sectional shapes, their orientations are here referred to by the directions towards which their axes point and called axial orientations.

In studying the behaviour of I-OPT.P.1 one notices that the fluctuation of the descriptor H is within a small range of 0.2 only, whereas the major change in the form occurs in the proportions of the base area as it changes from a rectangle of 1.5×2.38 to a square. The square base area seems to indicate an indifference towards horizontal directions at an axial orientation of N.15°E. and at intervals of 90° thereof. The maxima height and width coincide with the minimum depth indicating a favourable axial orientation at S.15°-30°E. The cyclic repetitiveness can be attributed to the symmetry of the form along both axes. This characteristic is half as strong in all other progressions since they represent a single axis symmetry.

In I-OPT.P.2, H and W take equal values whereas D becomes relatively small at axial orientations of S.30°E to S. The other extremes occur at N.75°E where H and D take large values whereas W becomes very small. Both cases indicate a large favourable exposure at S.15°E. The angular descriptor X2 seems to vary between +45° and -45°. Negative values occur when the pitched element faces between S and N.15°W via W (Pitch orientation = form orientation + 90°), which shows that only a pitch of up to 45° facing between N and S.15°E via E is desirable.

The linear descriptors behave similarly in I-OPT.P.3 but the angular ones vary between 45° and 90°. Each of the two angular descriptors X1 and Y1 seem to become right angles when their respective elements face S to N via W, and depreciate to 45° when they face N.15°E to S.15°E via E, thus favouring an elemental inclination at the latter range of orientations only.

The fluctuation of the value of H is of smaller amplitude in the I-OPT.P.4. Its highest value coincides with that of W and with the lowest value of D; thus suggesting a form with considerable height and width but of a shallow depth with S.15°E axial orientation, thus favouring it. The angular descriptor X2 takes a value of 45° when its respective element is due N.15°E to S.15°E via E but drops to 0° when due S.45°W

and then shoots up to 75° . This spectacular change in value of the angular descriptor is not very significant since the corresponding value of W_1 is small, but it indicates that whereas intermediate values of 45° for angular descriptors of elements orientated between $N.15^{\circ}E$ and $S.15^{\circ}E$ via E are desirable; they are undesirable for orientations between $S.30^{\circ}W$ and $N.30^{\circ}W$ via W .

In I-OPT.P.5, the general behaviours of the linear elements are similar to those of the last progression, only the form is generally less elongated along its axis. Again, the graph shows a bias in favour of the axial orientation $S.15^{\circ} - 30^{\circ}E$. Considering the four angular descriptors we find that X_1 and Y_1 take one of the two values 60° and 75° , adopting the lower value between $N.30^{\circ}E$ and E elemental orientation. Descriptors X_2 and Y_2 vary between 0° and 60° . Each takes the value of 0° when its corresponding element faces between $S.15^{\circ}W$ to $N.30^{\circ}W$ via W , but appreciates to 45° when facing between $N.15^{\circ}E$ to $S.30^{\circ}E$ via E , thus showing 45° as the favourite inclination for the latter orientation.

1.5.2 The Progressional I Value Curves (see page VI.5 of next chapter)

The resemblance of these curves shows clearly the similar attitudes of the various progressions towards the variation in orientation. The different behaviour shown by I-OPT.P.1 can

be attributed to its two-axial symmetry.

It seems that most of the progressions yield their maximal I values at an E-W axis of orientation with I-OPT.P.3 yielding the highest, which suggests that this is an undesirable axial orientation.

A complete agreement between all curves is apparent on having their minima at the S.15⁰.E axis. The lowest value is given by I-OPT.P.4. This progression seems to continue to yield lowest I values of all progressions for all orientations. Thus, S.15⁰.E is an optimum axial orientation and progression 4 includes the most desirable forms.

1.5.3 Conclusions

The forms dealt with by the model can be described as tubular varying in shape of section and having a rectangular base. Each form has two end vertical elements. The number, inclinations and sizes of the other elements is decided by the shape of the section. From the analysis of the I-OPT.P. charts and the Progressional I-Value curves it is possible to set geometrical recommendations for forms of low over-21 insolation. It can be assumed that these forms, provided their elements have the necessary R and C values, can provide a more naturally comfortable internal thermal environment, whether in value or

duration of comfort, than forms of other geometries and orientations. It follows, therefore, that buildings of such forms would need less complementary thermal conditioning, providing long term economy.

Aiming at such objectives, and concluding from the past analysis, a rectangular section building should have a plan proportions of 5:10 with the longer side facing $S.15^{\circ}-30^{\circ}.E$. Otherwise a square plan is recommended. The height can be taken as 35% larger than the average of the plan dimensions. This means that, in this type of form, the height should always be the larger dimension. Similarly, a building with a single pitched roof should have a plan of 6:10 proportions with the longer side facing between S and $S.30^{\circ}.E$. A more square plan can be used for other orientations. The recommended average height of the form can be taken as 20% larger than the average of the plan dimensions. The roof should have a slope of 45° and face any direction between N and $S.15^{\circ}.E$ via E. Otherwise, the roof should either be horizontal or of a small slope.

When using a form with a triangular section, its section would preferably be a right angle triangle. Its plan proportions should be 10:22 with the triangular shaped elements on the longer sides and facing $S.15^{\circ}.E$ and $N.15^{\circ}.W$. A value for the vertex height can be taken as 40% larger than the average of

the plan dimensions, and not smaller than any of them. The non-vertical element should have a slope of 45° and orientation between $N.15^{\circ}.E$ and $S.15^{\circ}.E$ via E.

A double pitched roof form should have a square shaped or 7:10 proportions plan, with the longer dimension facing S to $S.30^{\circ}.E$. A recommended height of the vertex is 20% larger than the longer plan dimension. Of the two planes of the roof, the larger one should have an inclination of 45° and face between $N.15^{\circ}.E$ and $S.15^{\circ}.E$ via east and the other should be horizontal, with the ratio of their areas around 1:5.

A form which section indicates two inclined walls and a double pitched roof, should have rectangular plan proportions of 1:2, with the vertical elements at the longer sides and facing $S.15^{\circ}.E$ and $N.15^{\circ}.W$. For other orientations, a more compact plan should be used. A recommended height of the vertex is 15% larger than the average of the plan dimensions. Each of the sloped walls should have an inclination of around 75° . The ratio of the areas of the roof planes should be around 1:3 with the larger plane inclined at an angle of 45° and facing between $N.15^{\circ}.E$ and $S.30^{\circ}.E$ via E, the smaller one being horizontal.

In general, exposure to $S.15^{\circ}.E$ is preferable to other directions. And a form type with four vertical walls and double

pitched roof is more favourable than other types considered from the point of view of the over-21 insolation.

1.5.4 The RC Optima Progressions (RC-OPT.P.) (See Figs. V.5-9)

The descriptors behaviour in these progressions, in general, follows a more regular pattern than in the I optima progressions. This regularity is due to the symmetry of the R and C data values about the N/S axis. Moreover, the various descriptors tend to fluctuate in a smaller amplitude.

In RC-OPT.P.1, H remains constant throughout whereas W and D oscillate between 2.2 and 2.5 yielding a square base at $N.45^{\circ}E$ and $S.45^{\circ}E$ axial orientations. Studying the axes along which extremities occur, one can detect a favourable tendency for exposure along the N/S axis. The behaviour of the three linear descriptors of RC-OPT.P.2 resembles that of their counterparts in the previous progression. The angular descriptor X2 fluctuates between -15° and $+15^{\circ}$ taking the negative value when its corresponding element faces E, to W via S, suggesting undesirability of these orientations for inclined elements, and a preference to a 15° inclination towards W to E, via N.

RC-OPT.P.3 takes the shape of a wide but shallow in depth

form for all orientations. It adopts its widest and relatively high but at the same time shallowest version when at N axial orientation, thus favouring it. The two angular descriptors seem to take one of two values 45° and 60° ; each becoming 60° when its corresponding element faces between E and W, via S, thus staying at intermediate inclinations throughout.

The angular descriptors of RC-OPT.P.4 seem to prefer lower values of angular descriptors. Each of these takes the value of 45° for an elemental orientation of S. 30° .E to S. 30° .W via S but stay at 30° for all other orientations. behaviour of the linear descriptors of this progression indicates a desirability for a N/S axial orientation and shows the E/W axis as one to avoid exposure to.

Similar conclusions on orientational axes can be drawn from RC-OPT.P.5. A significant character of this progression is that each two of its angular descriptors stay at one steady value. X1 and Y1 take the value of 75° and X2 and Y2 the value of 30° .

1.5.5 The Progressional RC-Value Curves (see Fig. V.10)

Once more in these progressions apparent similarity in pro-

gressional attitudes towards orientational variation is fairly clear. They all seem to indicate two favourite axes of orientation, E/W and N/S. Two undesirable axes are also suggested as being $N.45^{\circ}.E$ and $S.45^{\circ}.E$.

RC-OPT.P.4 and RC-OPT.P.5 seem to yield similar values for all orientations. Moreover, these values are by far the lowest in the chart which acts in favour of the two progressions 4 and 5.

1.5.6 Conclusions

By computing the R and C values of a form, we are in effect evaluating the amounts of materials necessary for its construction, from a thermal viewpoint. A form geometry which yields small R and C values is, therefore, economical to build. For each type of form handled by the model there is a certain range of geometrical properties which would result in an economical use of materials. A box-like, rectangular section building, should have a plan of 9:10 proportions. The longer sides should face N and S. For other orientations a square plan can be recommended. The height can be taken as 25% less than the average of the plan dimensions.

Similar plan proportion and orientation can be used for a form with a single pitched roof. Its average height should also be 25% smaller than the average of the plan dimensions. A

recommended slope of the roof is one of 15° and an orientation between $N.75^{\circ}.W$ and $N.75^{\circ}.E$ via W .

When using a form with a triangular section, its rectangular base should have the proportions of 1:2 when the long sides face N and S , and 5:6 when they face E and W . The two vertical elements should be at the longer sides and the two sloped elements should have inclinations of 60° , decreasing to 45° when facing NW and NE .

A recommended plan for a form with a double pitched roof is one of 9:11 proportions, with the long sides facing N and S . Otherwise a square plan should be used. The height of the vertex can be taken as 20% less than the average of the plan dimensions. The two planes of the roof should have roughly equal areas, and slopes of 30° facing E and W .

A form with two non-vertical walls and a double pitched roof should have its plan square shaped or of proportions 4:5, with the two vertical and opposite elements on the longer sides and facing N and S . Height of the vertex could be taken as 25% less than the average of the plan dimensions. The two sloped walls should not adopt an angle of less than 75° . And the roof planes should slope at an angle of 30° .

In general, the last two form types can be considered as the

most favourable from the point of view of the geometry R and C values.

2. Interpretation of Geometrical Proportions into Actual Dimensions

The recommended geometrical form and its proportions can prove to be cumbersome to make use of in practice, unless systematically interpreted into actual dimensions relating to the required volume to be contained by the building.

To find a relationship between the proportions of a form and its dimensions we consider a rectangular form of constant proportions but variable in size. Assuming that it adopts the volumes V_1 , V_2 , V_3 and V_4 , and that its proportions of height; depth; width are 1:1.5:2, the following cases are possible :

First case:

$$\begin{aligned} H_1 &= 2 & D_1 &= 3 & W_1 &= 4 \\ V_1 &= 24 \end{aligned}$$

Second case:

$$\begin{aligned} H_2 &= 4 & D_2 &= 6 & W_2 &= 8 \\ V_2 &= 192 \end{aligned}$$

Third case:

$$\begin{aligned} H_3 &= 6 & D_3 &= 9 & W_3 &= 12 \\ V_3 &= 648 \end{aligned}$$

Fourth case:

$$\begin{aligned} H_4 &= 8 & D_4 &= 12 & W_4 &= 16 \\ V_4 &= 1536 \end{aligned}$$

From the above:

$$\begin{aligned} & H_1 : H_2 : H_3 : \dots H_4 \dots H_n \\ & 2 : 4 : 6 : 8 \\ \text{or} & H_1 : 2H_1 : 3H_1 : 4H_1 \dots nH_1 \end{aligned}$$

$$\begin{aligned} \text{and} & V_1 : V_2 : V_3 : V_4 \dots V_n \\ & 24 : 192 : 648 : 1536 \end{aligned}$$

$$\text{or} \quad 1 \times 24 : 8 \times 24 : 27 \times 24 : 64 \times 24$$

$$\text{or} \quad V_1 : 2^3 V_1 : 3^3 V_1 : 4^3 V_1 \dots n^3 V_1$$

It can be seen from the above that H and V change following two different progressions. They can be related by the following

equation:

$$\frac{H_n}{H_1} = \sqrt[3]{\frac{V_n}{V_1}}$$

or

$$H_n = \sqrt[3]{\frac{V_n}{V_1}} \cdot H_1$$

Replacing V_1 by 10 which is the constant volume value used in all the progressions, and taking H as the value of a linear descriptor of any form in the progression,

$$H_n = \sqrt[3]{\frac{V_n}{10}} \cdot H$$

Where:

H_n is the value of the required dimension

V_n is the required volume of the form

H is a recommended proportion

$\sqrt[3]{\frac{V_n}{10}}$ is a conversion factor.

2.1 The Conversion Chart

For practical purposes the above relationship is plotted as a chart in the next chapter (see page VI.11). This chart covers volumes ranging between 10 m^3 and $10,000 \text{ m}^3$. It can also be used for larger volumes by considering the volume scale

as representative of units of $1,000 \text{ m}^3$, and the conversion factor scale of units of 10.

Thus by deciding on the volume of the envisaged building, the designer finds the conversion factor, by which the recommended proportions have to be multiplied to find the dimensions of the recommended geometrical form in metres.

CHAPTER VI

THE GENERATIVE MODEL AND ITS APPLICATION

1. The Generative Model

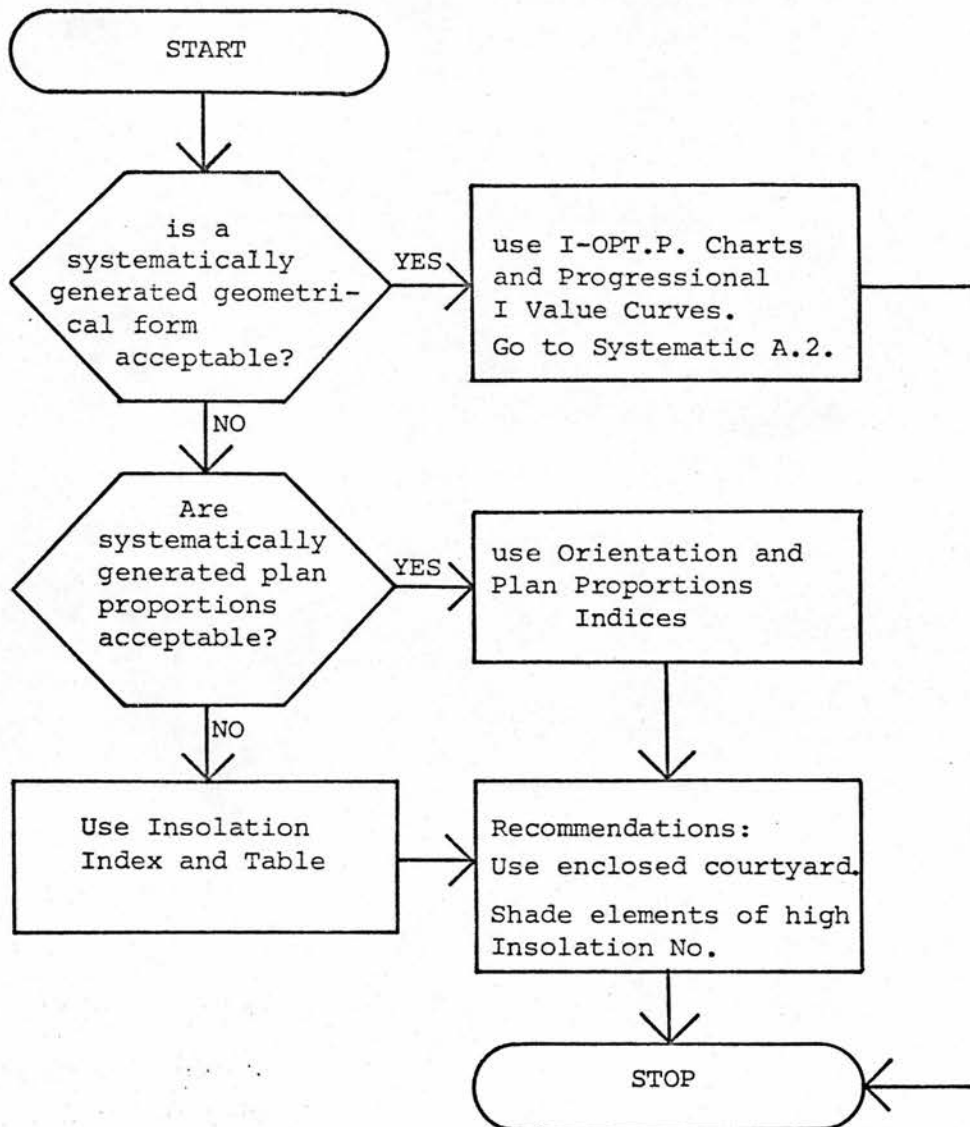
The model consists of 19 charts and indices organized into four sets. Each set aids the designer in deciding on a certain number of building parameters as follows :

- A. Form geometry and orientation.
- B. External colour, materials choice and composition of the element.
- C. Design of windows and shading devices.
- D. Further thermal control of the building.

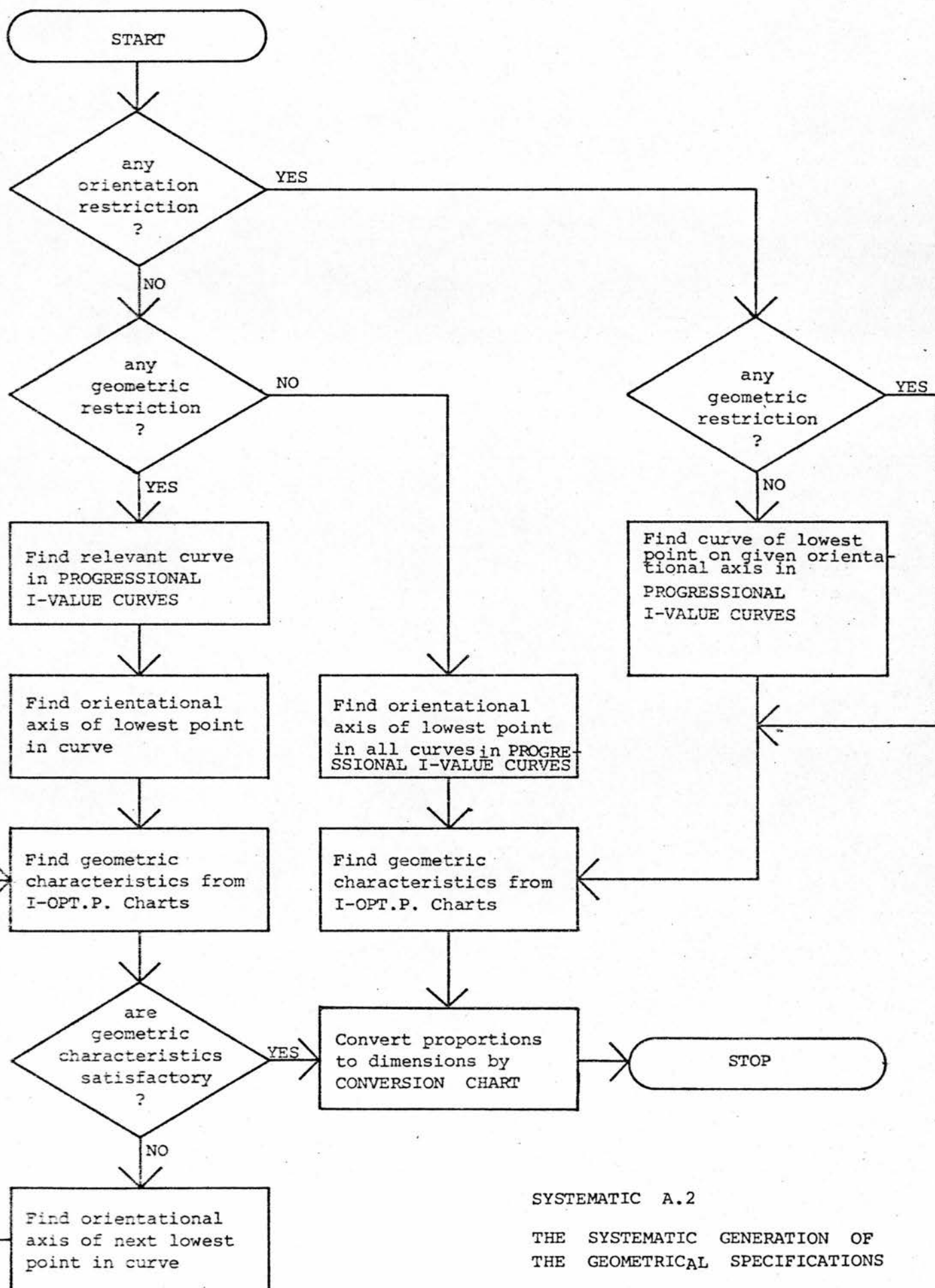
The method of use of each of the first three sets is illustrated by a systematic flow chart. The last set consists of two charts which are more informative than generative. They can be used without the help of a flow chart.

A. Form Geometry and Orientation

This set provides for three alternative methods. A choice can be made according to the following flow chart.

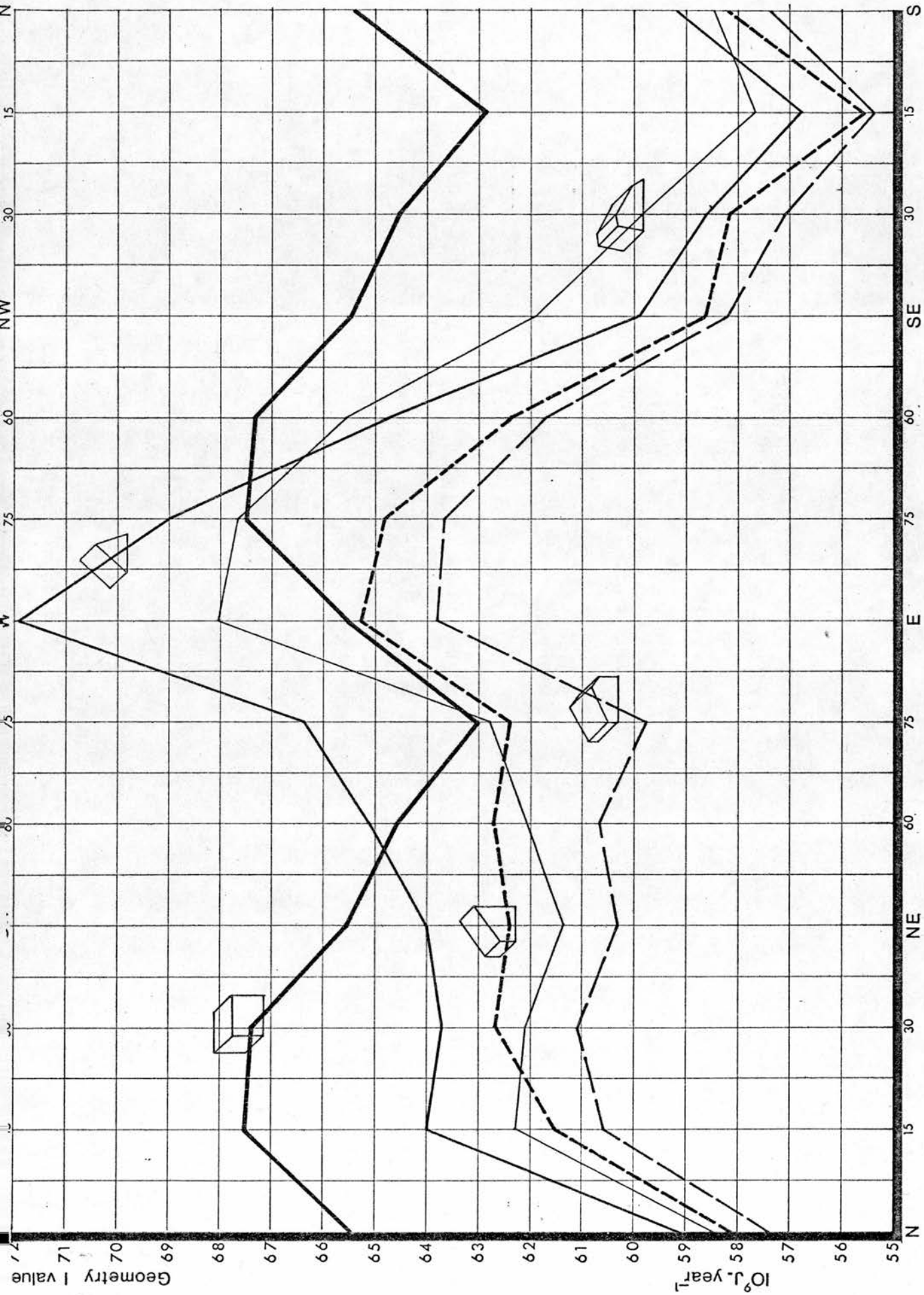


Systematic A.1

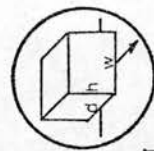
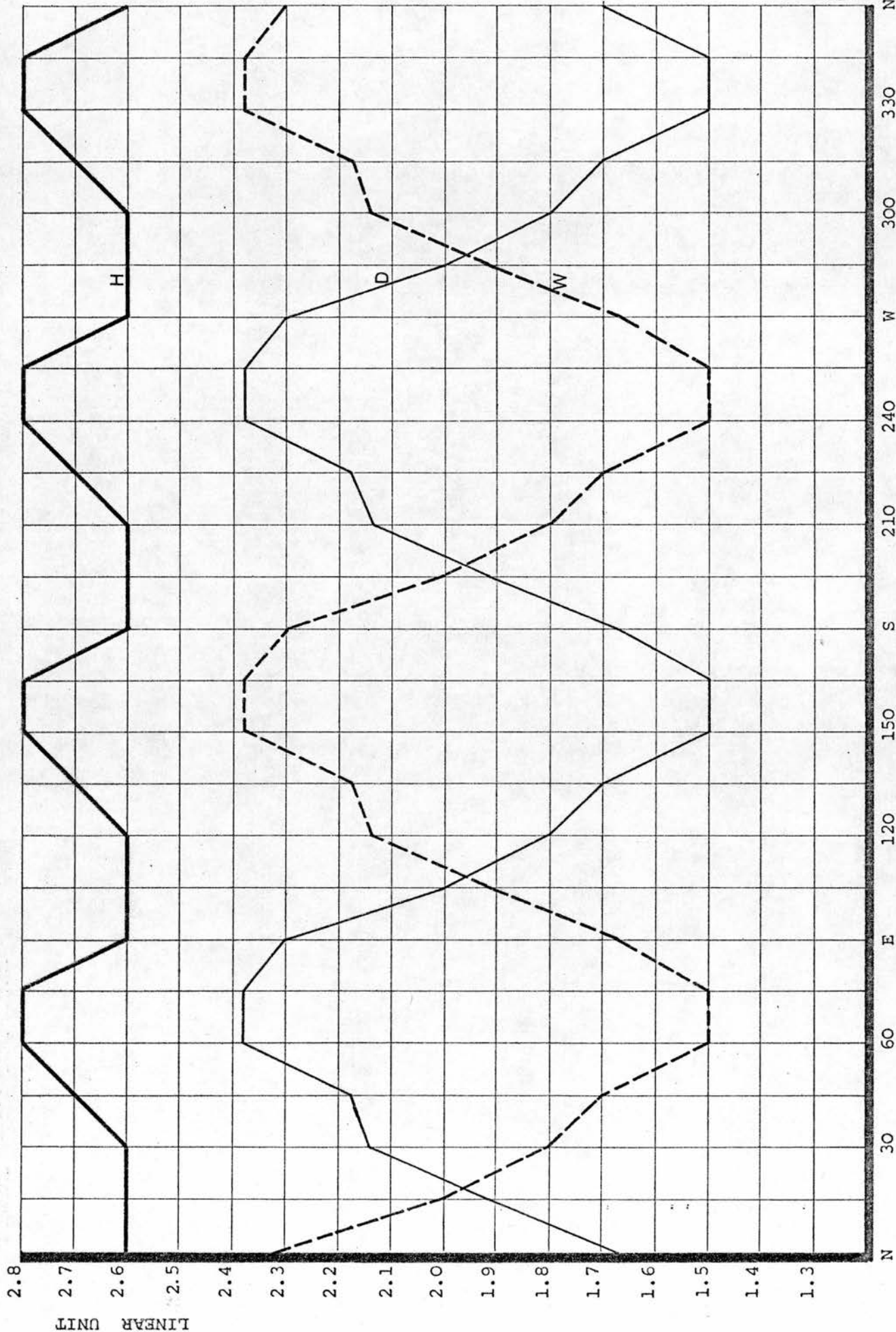


SYSTEMATIC A.2

THE SYSTEMATIC GENERATION OF
THE GEOMETRICAL SPECIFICATIONS

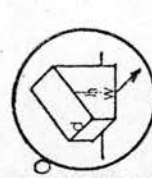
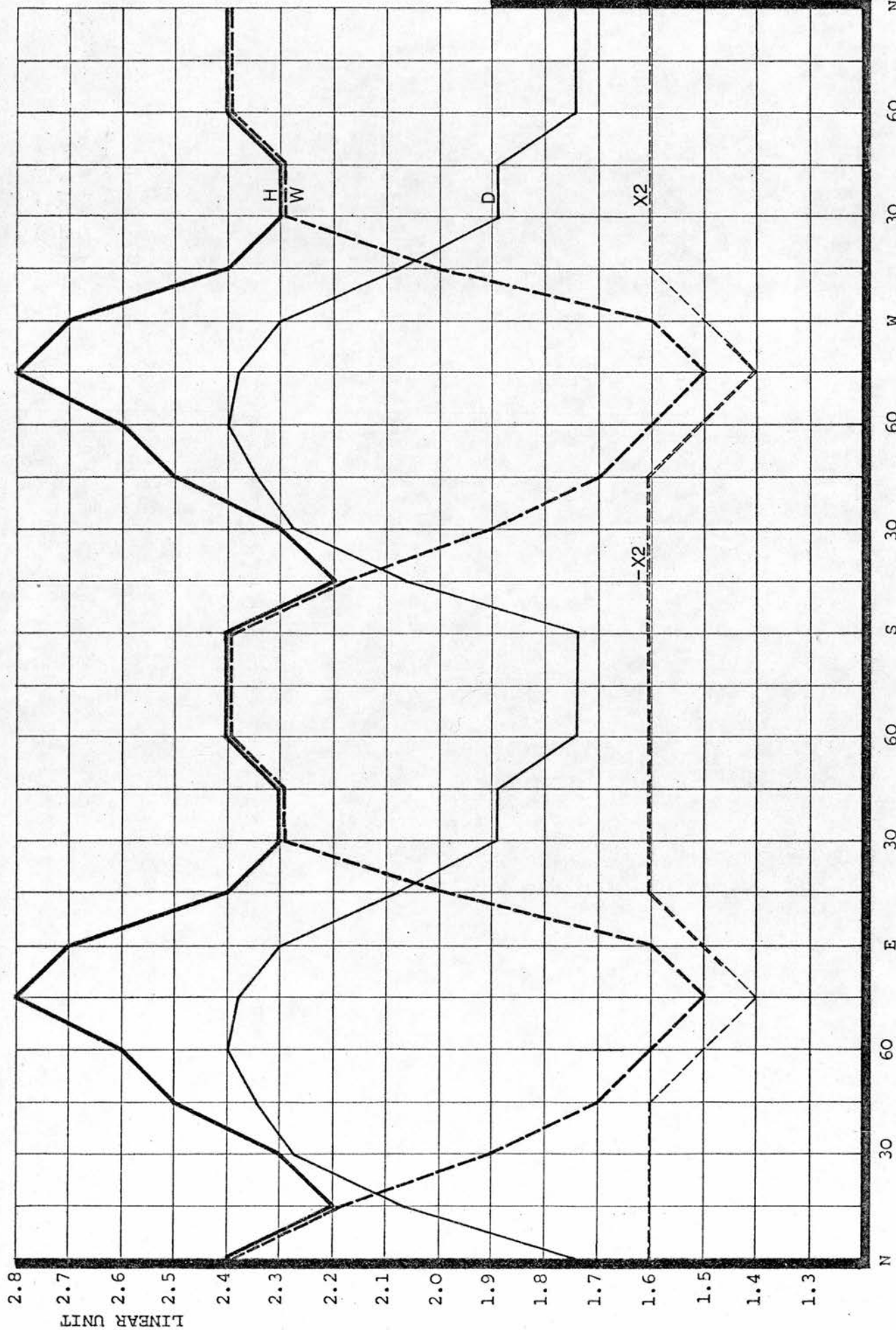


The Progressional I-Value Curves



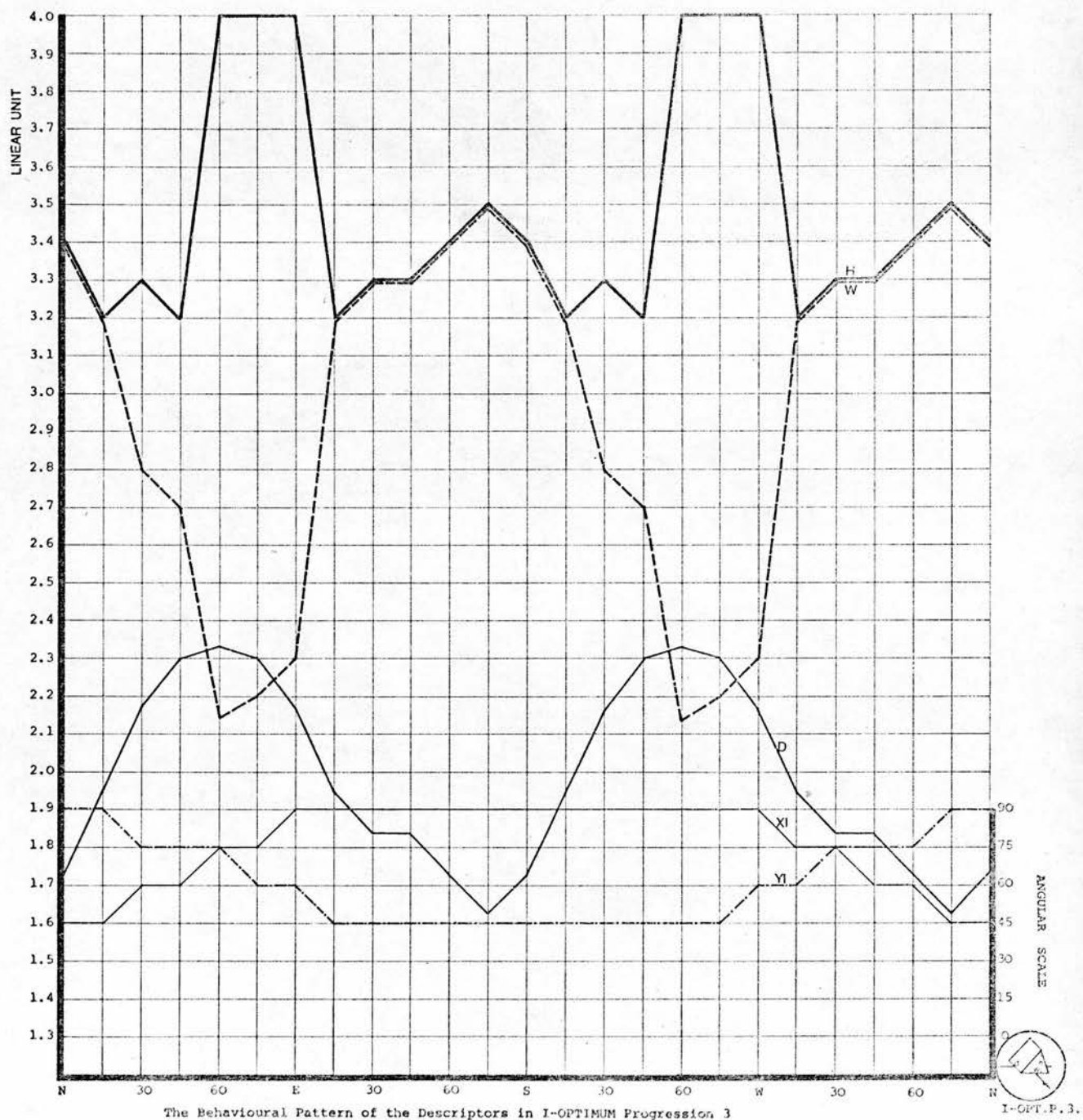
The Behavioural Pattern of the Descriptors in I-Optimum Progression 1

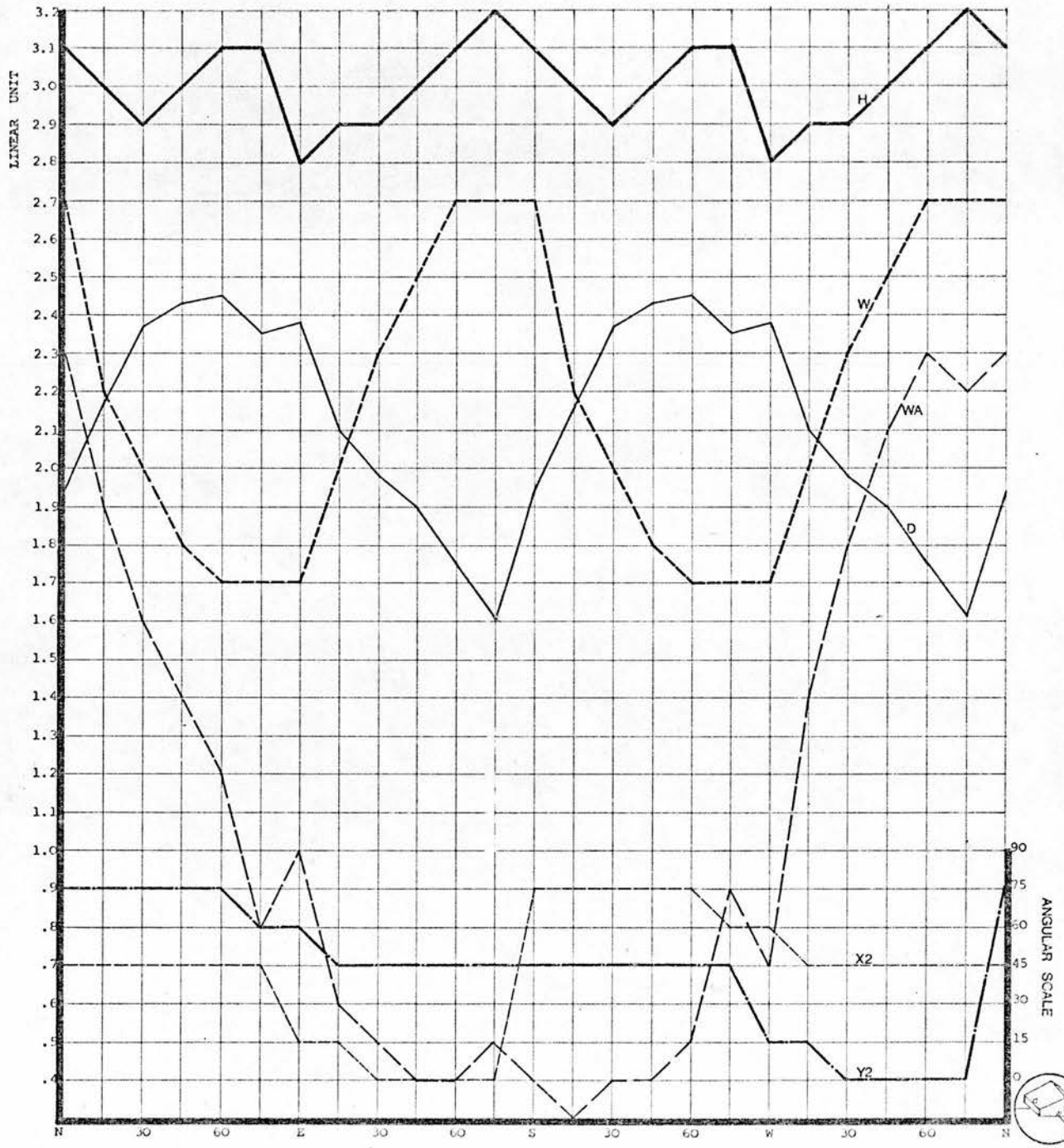
I-OPT.P.1



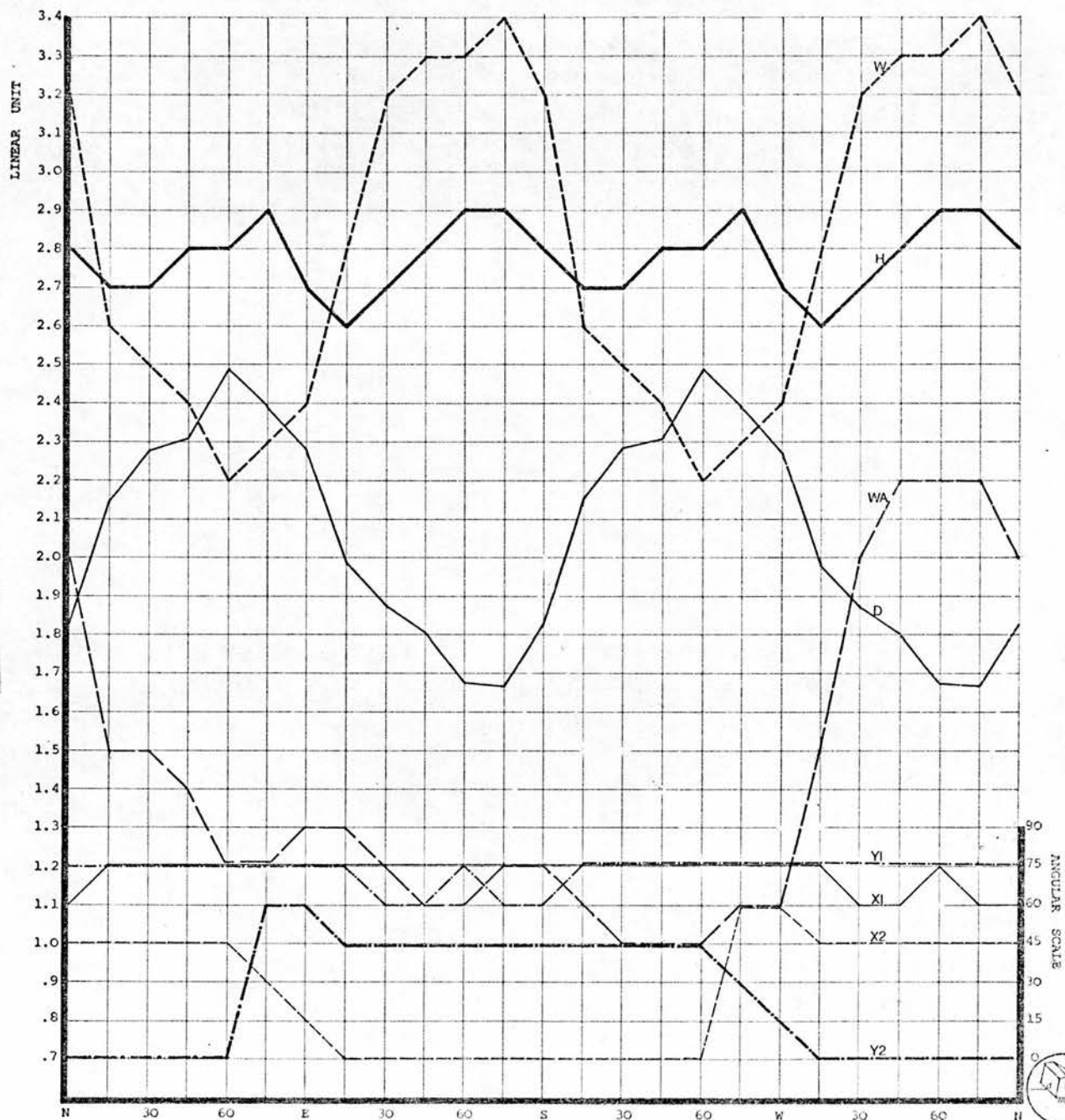
I-OPT.P.2

The Behavioural Pattern of the Descriptors in I-OPTIMUM Progression 2

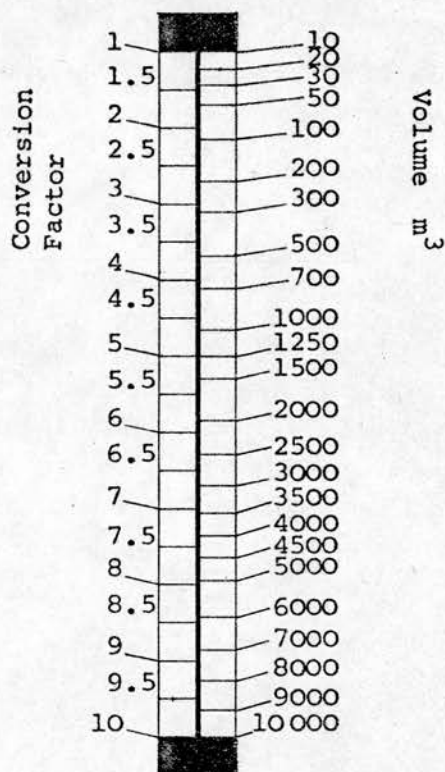




The Behavioural Pattern of the Descriptors in I-OPTIMUM Progression 4

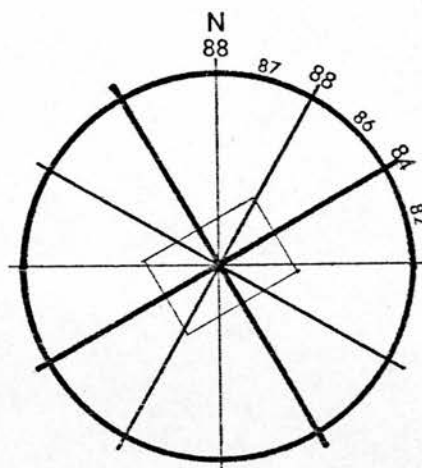


The Behavioural Pattern of the Descriptors in I-OPTIMUM Progression 5



The Conversion Chart

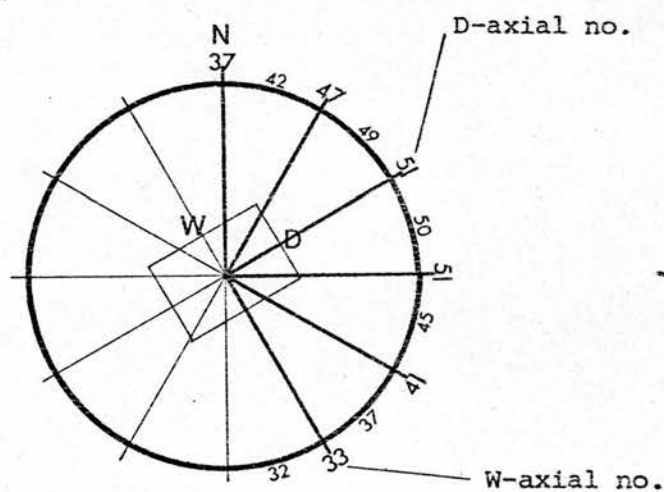
Knowing the required volume, the factor can be found which should be multiplied by the recommended proportions to give the actual dimensions in meters.



Orientation Index

Each two perpendicular axes represent one axial orientation of a rectangular plan form.

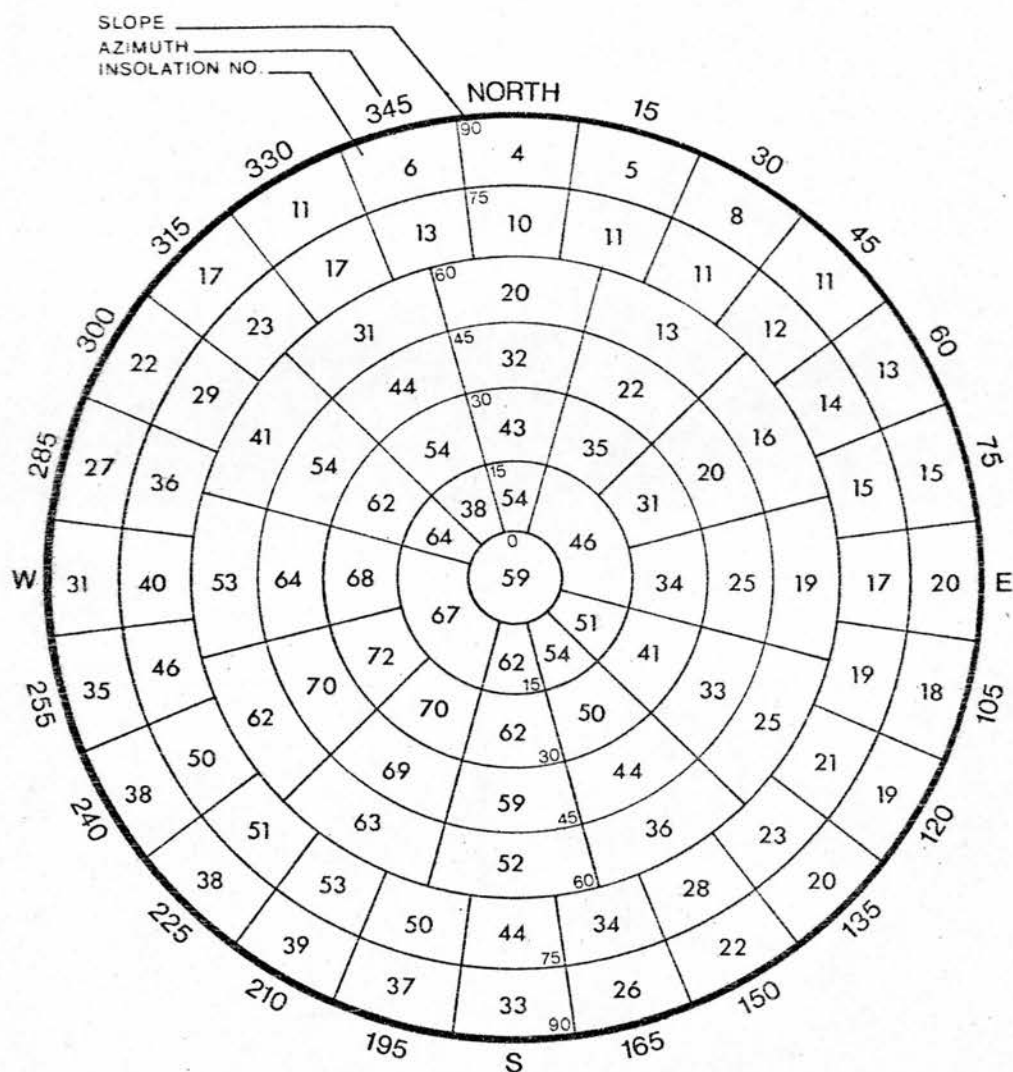
Optimum axial orientation has minimum number



Plan Proportions Index

Knowing the axial orientation of a rectangular plan, its optimum proportions can be found by :

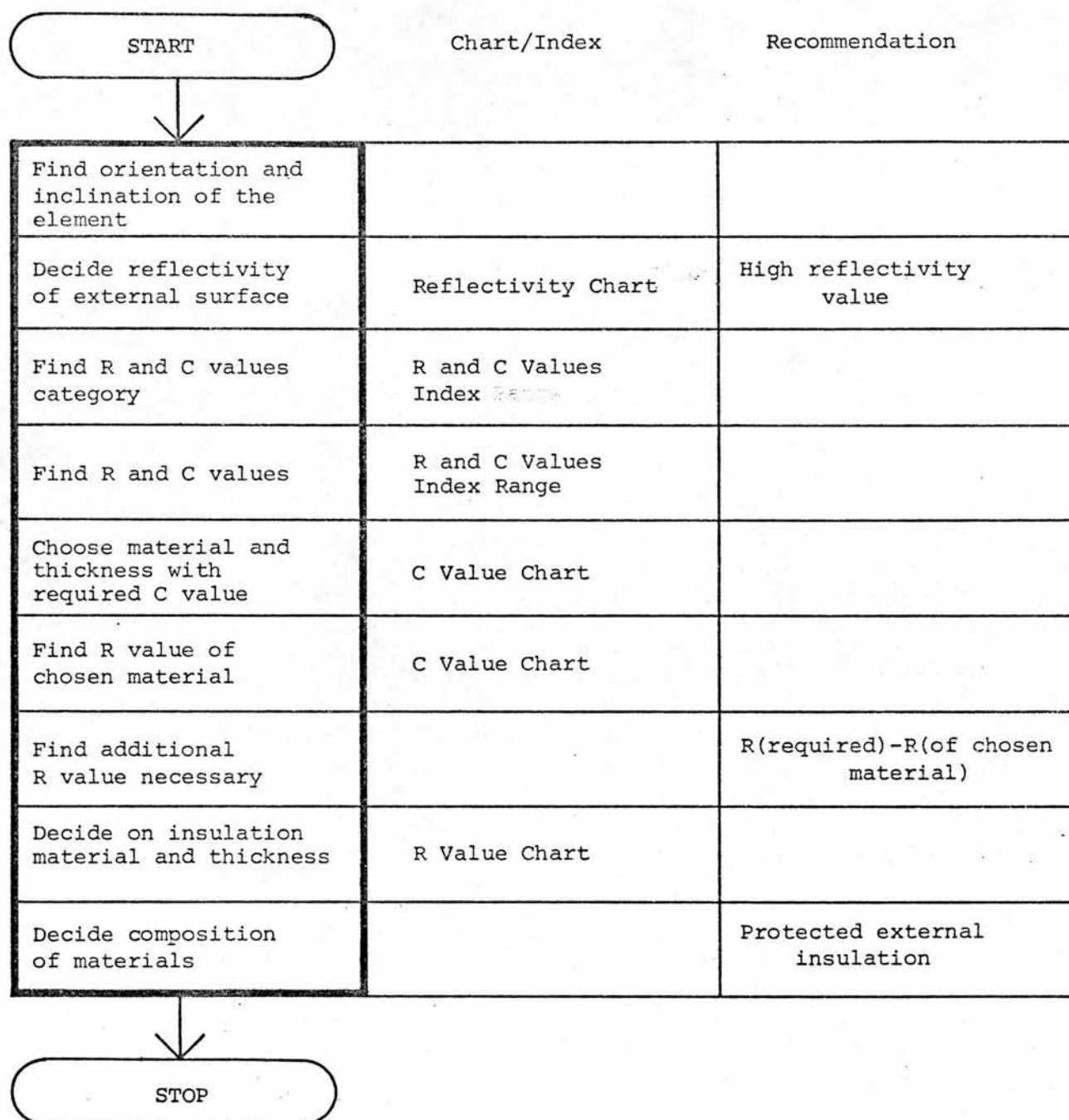
$$\frac{D}{W} = \frac{\text{W-axial no.}}{\text{D-axial no.}}$$



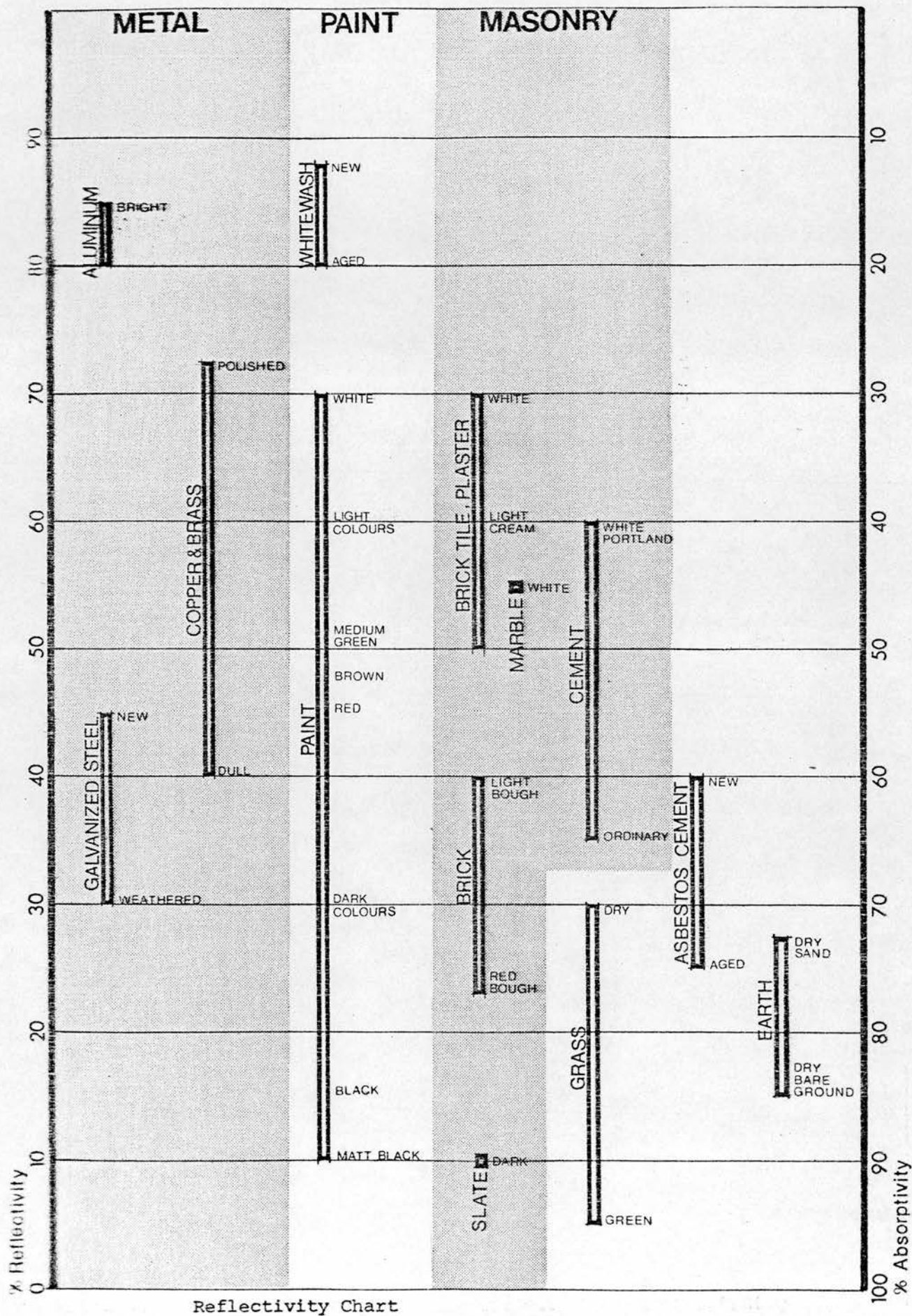
Insolation Index

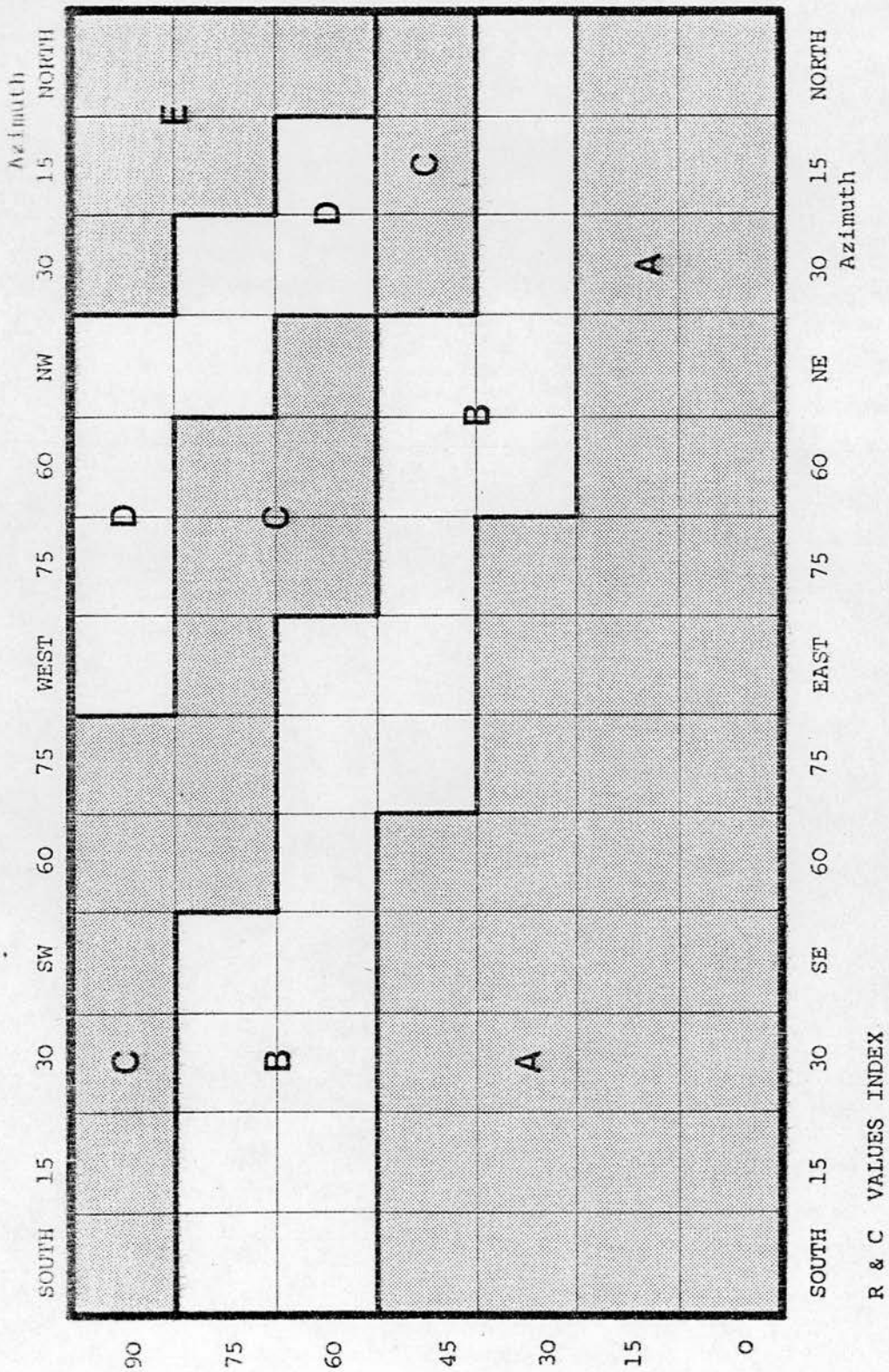
[illegible]

Insolation Table

B. External Colour, Materials Choice and Composition of the Element

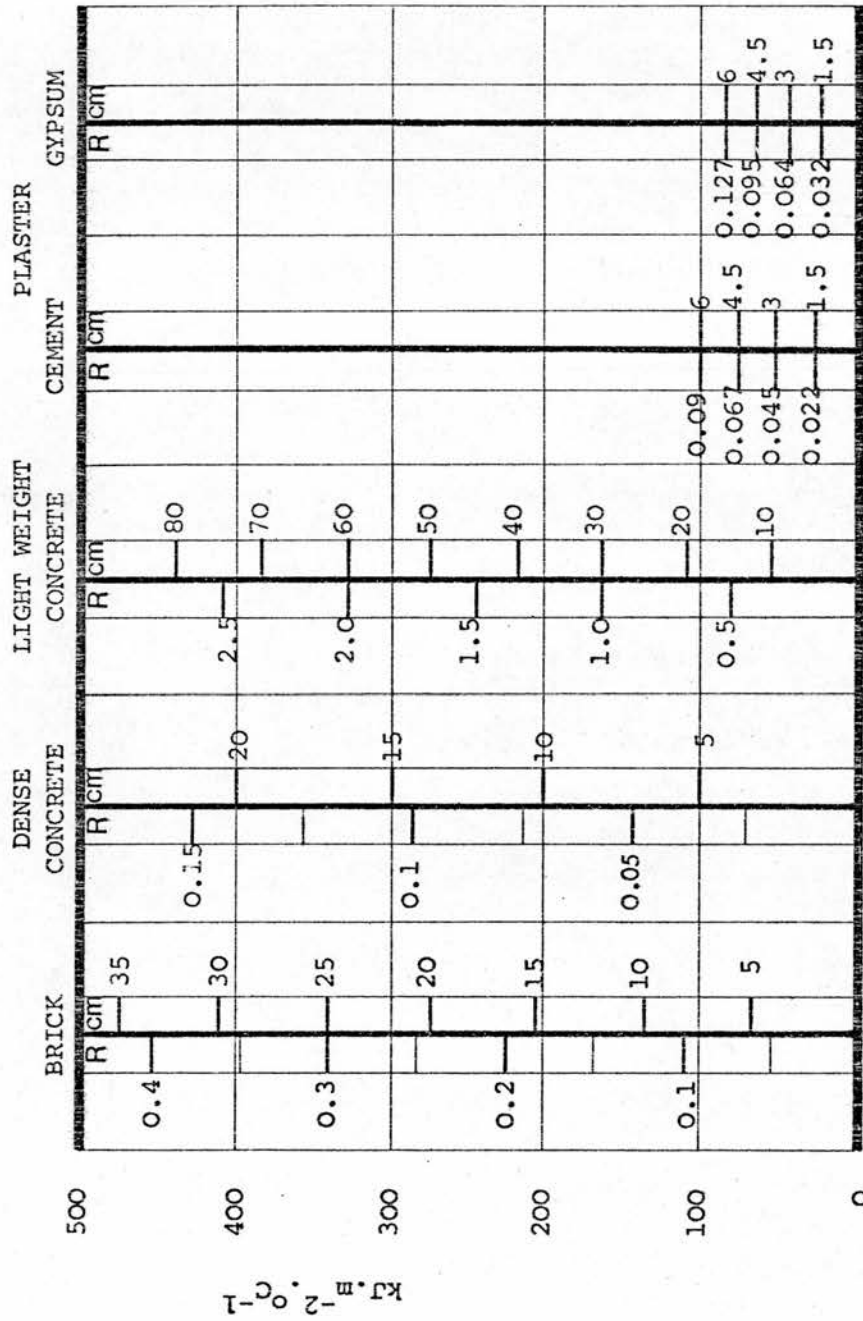
Systematic B



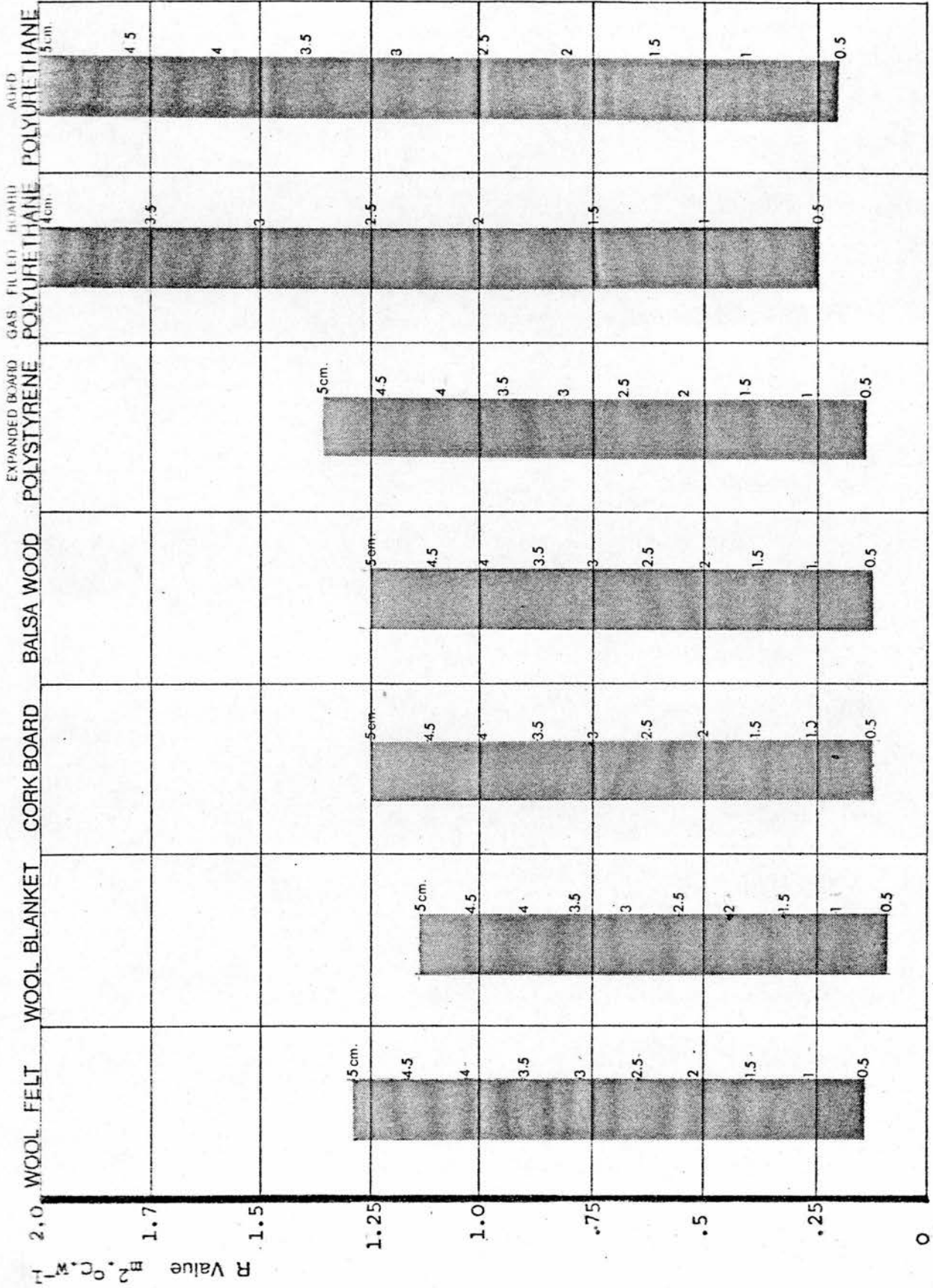


REFLECTIVITY %	A		B	C	D	E
85	R	0.90	0.86	0.82	0.77	0.72
	C	228	219	208	197	185
70	R	1.15	1.07	0.98	0.89	0.79
	C	291	271	250	227	200
55	R	1.4	1.28	1.15	1.02	0.86
	C	353	324	292	258	220
40	R	1.66	1.49	1.31	1.15	0.93
	C	406	385	335	293	240

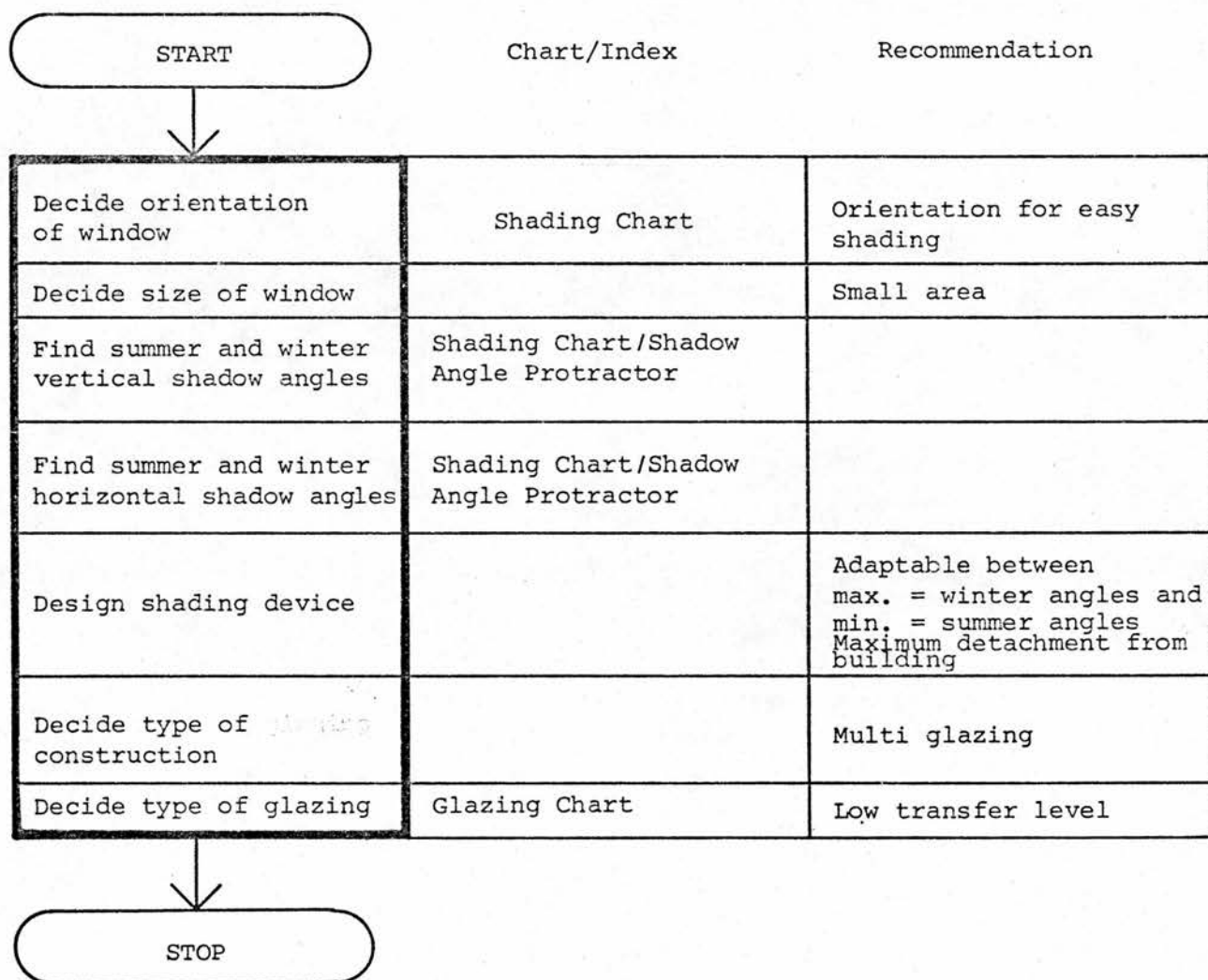
R & C VALUES INDEX RANGE



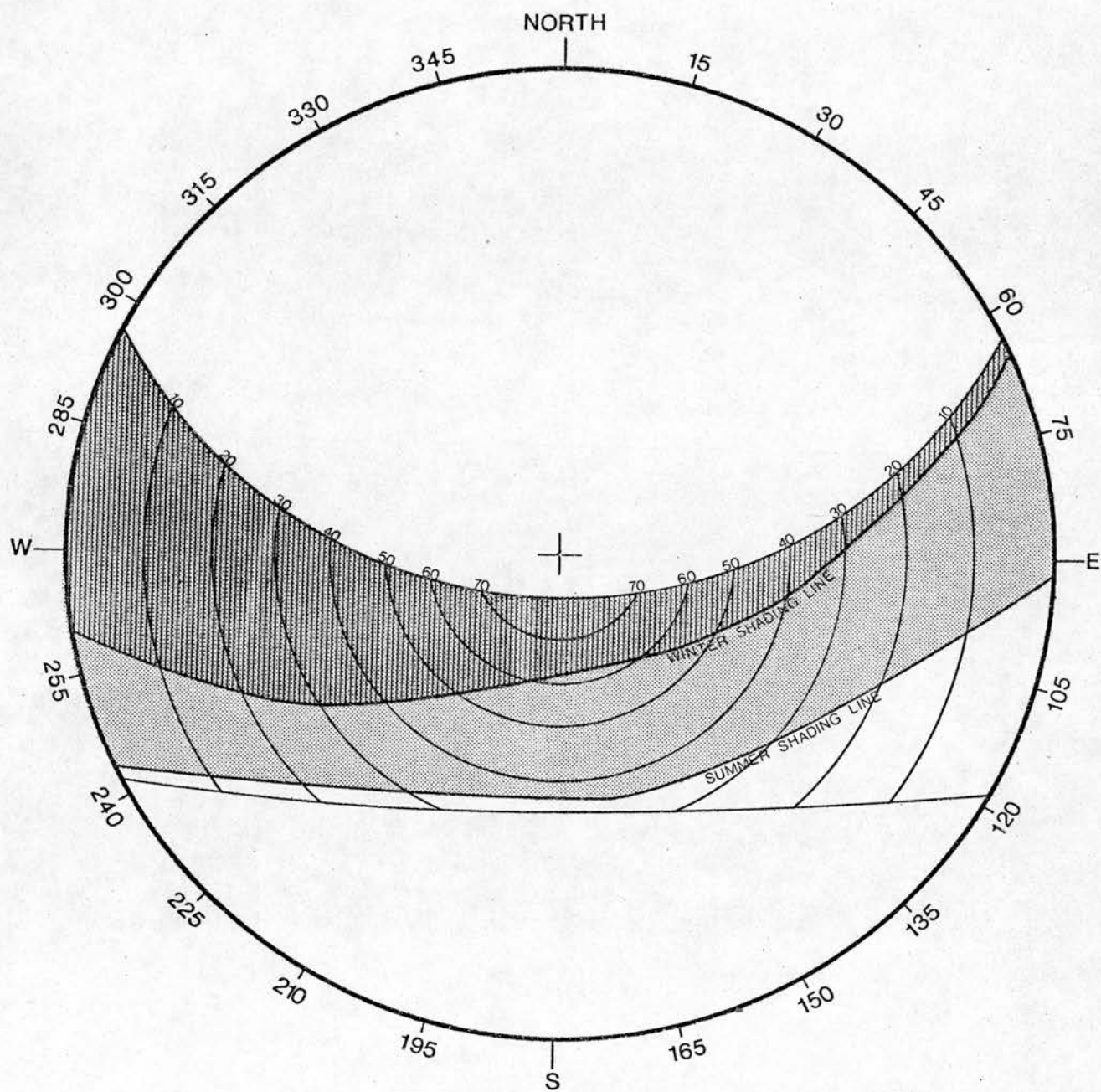
C VALUE CHART



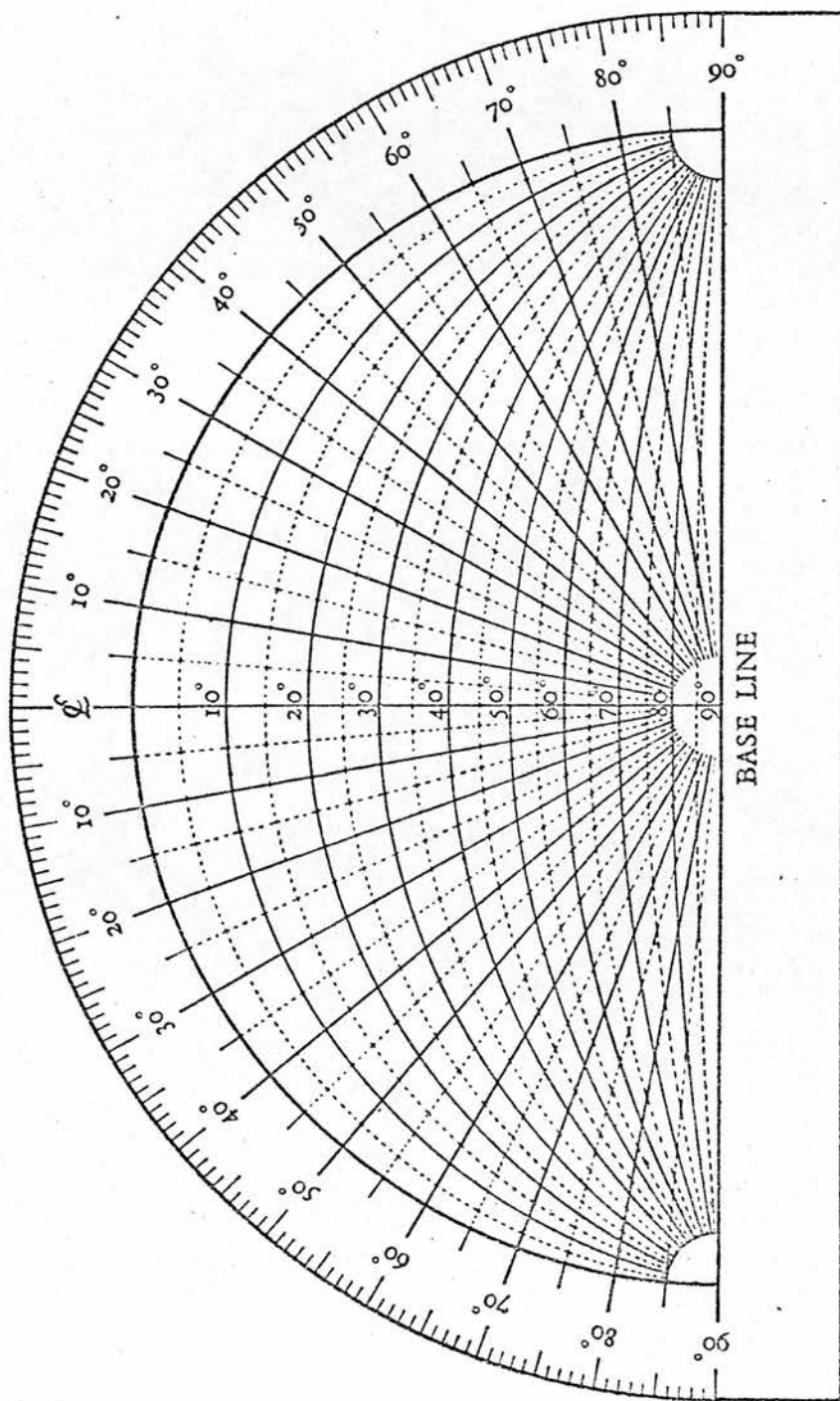
R Value Chart

C. Design of Windows and Shading Devices

Systematic C



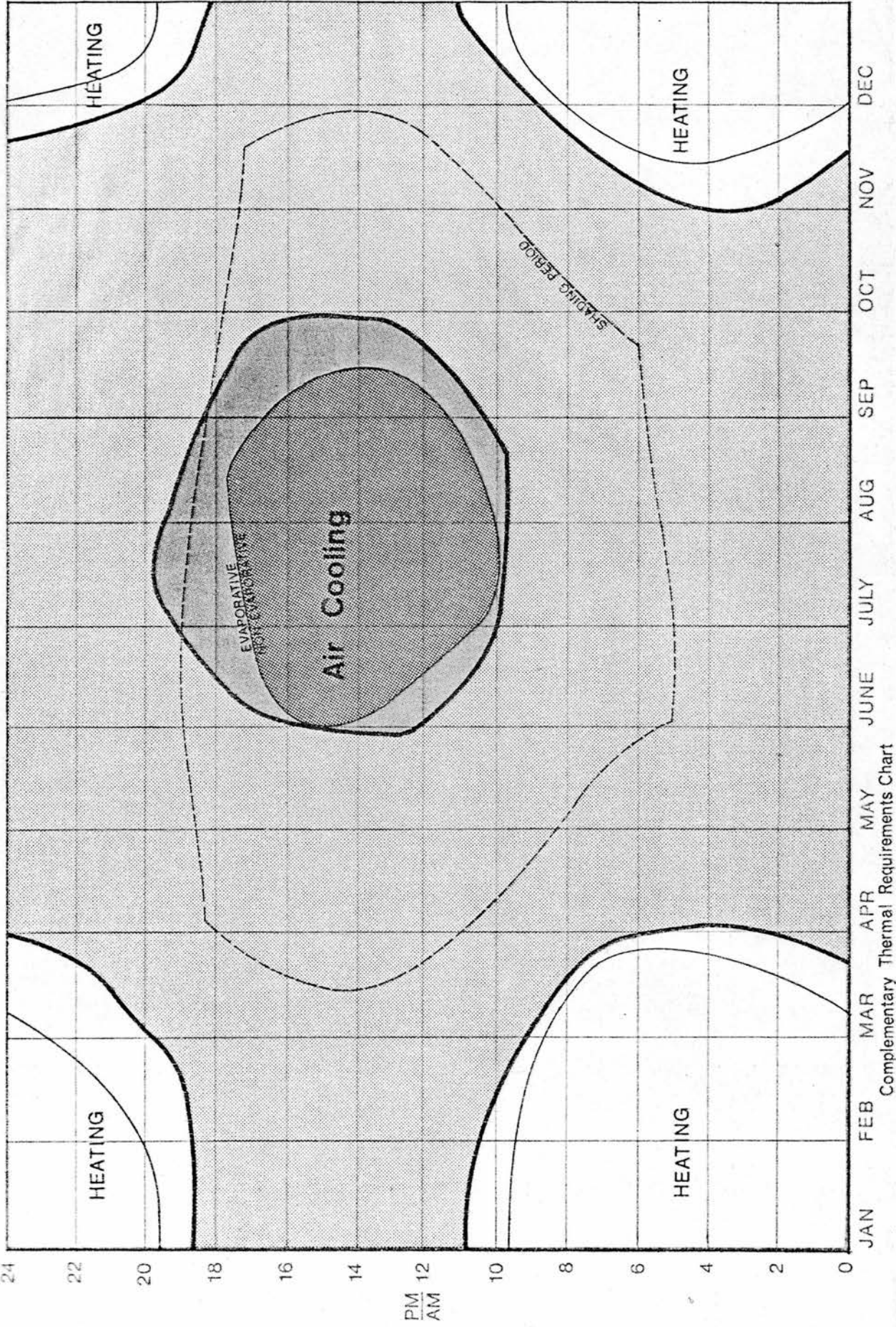
The Shading Chart

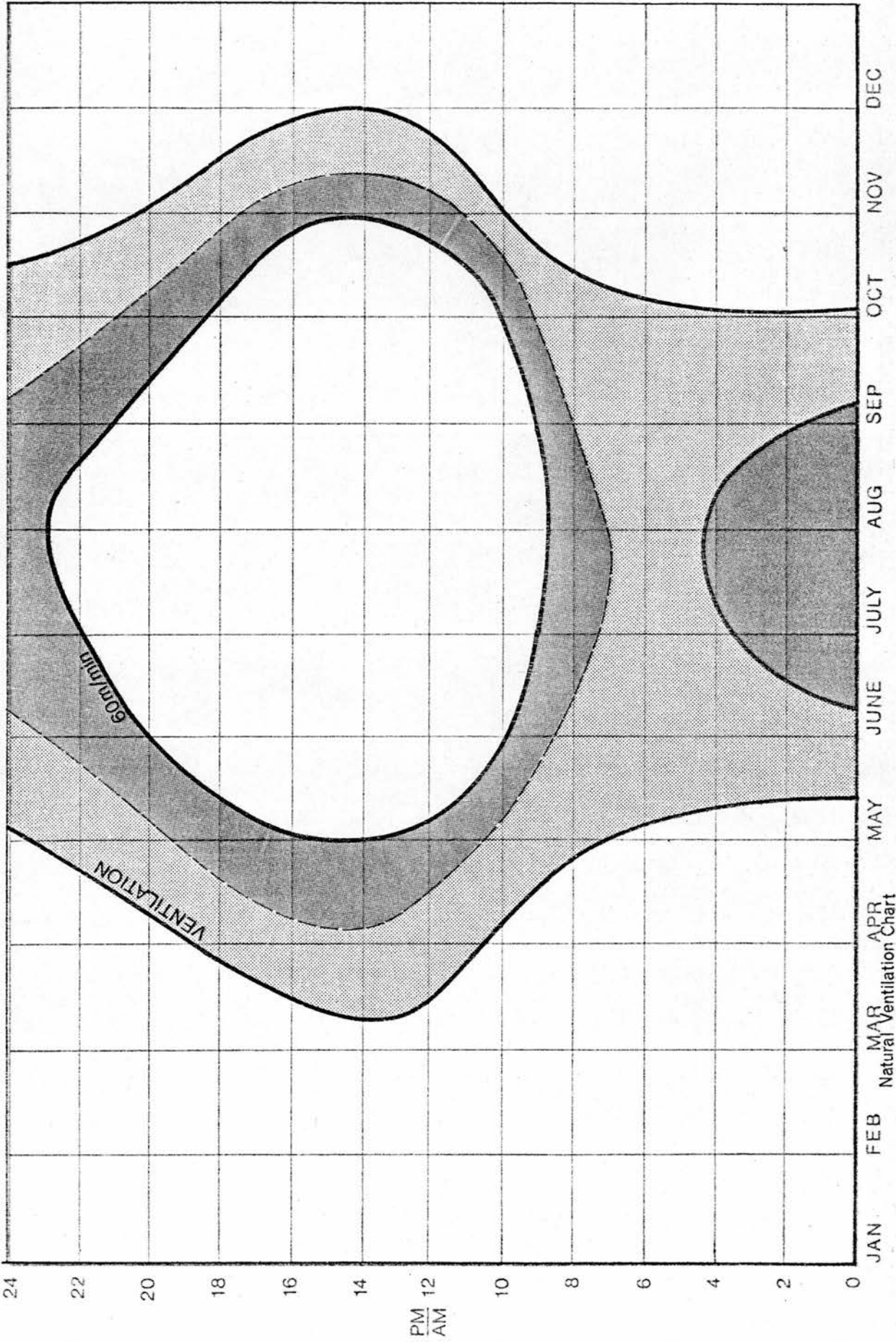


The Shadow Angle Protractor



The Glazing Chart





2. Implications of the Model and its Application to
A Design Problem

The generative model developed by this thesis probably does not go as far as some designers would like by suggesting final constructions of elements instead of R and C values, and actual shading devices instead of shadow angles. A similar argument can be put forward concerning the Insolation, Orientation and Plan Proportions Indices. But it should be noted that the approach adopted here aims not only at protecting the designer from producing bad thermal designs, but also at providing a design atmosphere with as much freedom as would allow the competent designer to use his ingenuity in producing a good architectural solution from all aspects. To achieve this, the model concentrates on what can be termed as "performance specifications" of the building which, if satisfied, can result in a well thermally designed building.

Being devised for use in design, the model can be best tested by application to a design problem, and measurement of the level of comfort achieved by the internal thermal environment of the constructed building. This method, however, is a long term one. Immediate evaluation can be made by a discussion of the model and its implications, its application to a design problem and a theoretical assessment of the outcome. It must be emphasised

here that the full potential of the model can only be exploited after achieving familiarity with it.

A. Form Geometry and Orientation

The decisions on the parameters dealt with in part A are likely to be strongly influenced by many factors other than thermal e.g. an urban grid can have a detrimental effect on the orientation, and economy can limit the range of geometrical forms the building can adopt. For this reason this part is constructed to allow for flexibility in application, which enables it to deal with problems of various complexities or constraints. Its use starts by Systematic A.1 (page VI.3). This is a flow chart devised to guide the designer in choosing one of three alternative methods of decision making on the form geometry and orientation, taking account of the non-thermal constraints. The choice in this chart is made by consideration of the amount of constraints on the geometry. It starts by assessing the acceptability of a systematically generated geometrical form or plan proportions, and leads to the use of one of the following three parts of the set.

I-OPT.P Charts and I Value Curves
(Pages VI 4-11)

Use of these is illustrated by Systematic A.2 (page VI.4) which provides four alternative ways of decision, each corresponding to one of the following conditions :

1. No restrictions
2. Restrictions on orientation only
3. Restrictions on geometry only
4. Restrictions on orientation and geometry

In all cases the function of the model is the systematic choice of a geometrical form out of five form types giving its recommended proportions and orientation. The forms and the orientations generated for each of the conditions are, however, different. The first condition, when no restrictions are applied, produces the optima of form type, proportions and orientation. The second results in an optimum geometrical form, in type and proportion, for the given orientation. The third yields optimum orientation and proportions for the given form type, and the fourth, when both geometry and form type are dictated, yields optimum proportions.

Knowing the design volume, and by use of the Conversion Chart

(page VI.11), the designer can find the appropriate conversion factor by which the proportions have to be multiplied to yield actual form dimensions.

For a further explanation of the practical aspects of this part, it is applied here to three problems with different constraints. (See following three pages).

As discussed above, the I value curves and I-OPT.P. charts involve five types of geometrical forms. They cover ranges of proportions where these forms are considered thermally optimal. The applicability of the charts in the design process is therefore considerably limiting, especially when we consider the infinite number of geometrical possibilities an architectural form can adopt. Moreover, the geometrical forms described by the charts generally fall within a small range of proportionality. The ratio of height to base area in I-OPT.P.1 varies between 2.6/3.85 to 2.8/3.57 only. And apart from I-OPT.P.5, the height seems to be the largest dimension in any of the described forms. This suggests that, when the designer is restricted to a height of two or three storeys, which is often the case in the housing scale, he is also limited to a relatively small plan area.

CASE 1

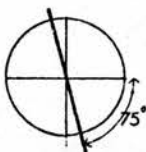
Constraints:

Orientational axis	None
Geometrical form type	None
Volume	6000 cu. m.

Recommendations:

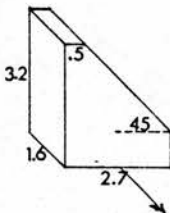
Source

Orientational axis



I-Value Curves

Geometrical form type



I-Value Curves

Geometrical form proportions

I-Opt. P.4

Dimensioning Factor

8.5

Conversion Chart

Final Recommended Form:

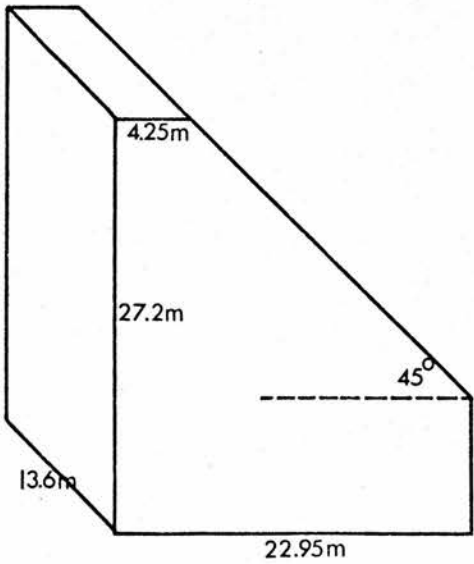
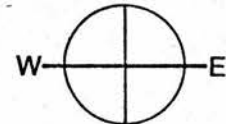


Fig.VI.1

CASE 2

Constraints:

Orientational Axis



Geometrical form type

None

Volume

640 cu. m.

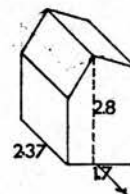
Recommendations:

Source

Geometrical form type

I-Value Curves

Geometrical form proportions



I-Opt. P.4

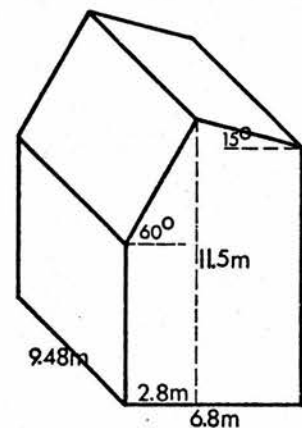
Dimensioning Factor

4

Conversion Chart

Final Recommended Form:

Fig.VI.2



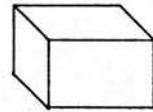
CASE . 3

Constraints:

Orientational Axis

None

Geometrical Form Type



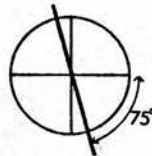
Volume

10,000 cu. m.

Recommendations:

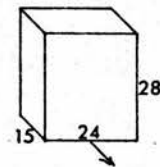
Source

Orientational Axis



I-Value Curves

Geometrical Form
Proportions



I-Opt. P.1

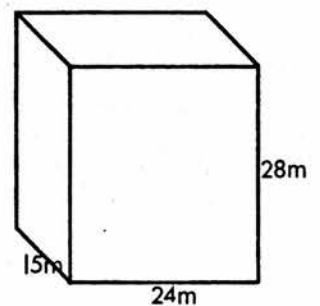
Dimensioning Factor

10

Conversion Chart

Final Recommended Form:

Fig.VI.3



Orientation and Plan Proportions Indices
(Page VI.12)

These indices provide an approach which is considerably more flexible than the former. It builds on the fact that the orientation of a rectangular plan can be represented by two perpendicular axes and provides a means of evaluation of this axial orientation. The values presented by the Orientation Index are only relevant when the Plan Proportions Index is used. This has the function of generating optimum plan proportions for any chosen axial orientation.

It is therefore possible to conclude that, by use of the proportions recommended for each orientation, the effect of the orientation can only vary by less than 8%. These indices, however, do not take into consideration the roof, a decision on the geometry of which can be made by referring to the Insolation Index.

Insolation Index and Table
(Page VI.13)

The Insolation Index is the most adaptable means of the set. It depends on placing values on planes of differing orientations and inclinations, with the least value indicating the optimum. This method leaves the designer the complete responsibility of assembling a geometrical form, and provides

him with a means of evaluating it.

The Insolation Table makes the evaluation of the form insolation value possible and can equally be used for evaluating the insolation of existing forms. Study of the index would result in a better understanding by the designer of the thermal problem, and therefore better designs. e.g. the value of the insolation number of an element demonstrates the importance of its external colour and the need to shade it. The use of the index and table is demonstrated in Chapter II (Figs. II.12 - 13) in evaluating the effect of a change of orientation of a form on its insolation value, and in Appendix VI in comparing the traditional and modern concepts of the house in Baghdad. Further use of the index is made in a design problem at the end of this chapter (Fig. VI.4).

B. External Colour, Materials Choice and Composition of the Element Pages (VI.14-19)

This set of charts and indices is concerned with the design of the opaque element, apart from its geometry. Its method of use is illustrated by Systematic B (page VI.14). It starts by the decision on the treatment of the external surface of the element. This is done by considering the reflectivities of a variety of surfaces to solar radiation. The Reflectivity

Chart (page VI.15) provides this information for surfaces common in building practice. Although the importance of the reflectivity of a surface is a function of the amount of solar radiation it is exposed to, the decision involving it can be treated in a manner independent of the geometry of the surface, i.e. orientation and inclination, assuming the undesirability of the absorption of solar heat, and therefore a high reflectivity value is recommended for all external surfaces. The ultimate recommendation of the chart therefore is a whitewashed external surface. On the other hand, considering the fact that two well shaded surfaces with different reflectivity values function similarly from the thermal point of view, the designer can use the recommendation with a certain amount of liberty by the use of shading.

After deciding on the external treatment of each element, the generation of the required R and C values becomes completely systematic. This step involves the R and C Values Index (page VI.16), which categorizes the elements according to their R and C values. By using the inclination and orientation of the element, one of five categories marked A to E can be found. By knowing the category, and using the reflectivity value found earlier, the recommended R and C values can be found from the R and C value Index Range (page VI.17).

The outcome of the procedure described above is in the form of two numbers, the R and C values representing the amounts of thermal resistance and capacity required to be contained by the element.

The last stage of this part of the model involves the interpretation of the R and C values into wall and roof constructions. This includes decisions on :

1. The specification of the materials, e.g. brick, stone, polyurethane.
2. The amount of each material.
3. The composition of the element.

Masonry materials, being of high densities, yield a high thermal capacity. At the same time, the amount of masonry required to provide the necessary thermal capacity has a considerable amount of thermal resistance. But it can be seen from the model that this thermal resistance will have to be supplemented by a further amount to form an R value equal to the required. This is best done by insulation materials, the application of which may have little effect on the total C value of the element. The designer, therefore, will have to specify two kinds of materials, one of heavy character e.g. concrete, brick, and one of insulating property e.g. polystyrene, corkboard.

The decision on the amount of heavy materials to be used can be made by using the C Value Chart (page VI.18), which also indicates the R value provided by this material. The R Value Chart (page VI.19) helps in deciding on the insulation and thickness required to supplement the thermal resistance in the element and restore its R value to the amount required.

As for the composition of the materials in the element, Systematic B (page VI.14) recommends external insulation for a higher time lag, which raises a constructional problem, since insulating materials applied externally will require some kind of protection. This can be provided by sheet materials like asbestos, otherwise the insulation can be sandwiched between two layers of heavy materials, with the thinner layer on the external side. Such decisions will probably be influenced by some technical matters like the dimensions of the brick or concrete block, the availability of sheet materials and the standard of workmanship. Moreover, different kinds of insulating materials have various applicabilities according to their nature. Thermal insulation can be found as loose fill, blanket, board, slab, foam.... etc. and the constructional details of the element will have to account for the property of the insulating material in question. The application of this

part of the model is further illustrated by the example at the end of the chapter (Figs. VI. 5-6 and Table VI.1).

C. Design of Windows and Shading Devices
(Pages VI. 20-23)

The third part of the model consists of a set of two charts and one protractor. Its use is guided by Systematic C (page VI.20), which starts with the decision on the window orientation. It is discussed in Chapter III that provided the window is appropriately shaded, its orientation can be governed by non-thermal needs, and therefore the only recommendation Systematic C provides in this respect is an orientation for easy shading of the window. This can be done by consulting the Shading Chart (page VI. 21) which shows that, unless with some vertically standing obstructors opposite the window, shading of an east or west orientation window can prove to be impossible.

As for the size of the window, it is recommended that it should be of small area. In this respect the smallest size window satisfying the non-thermal needs can be used, e.g. the provision of a certain level of natural light inside the space and the visual communication of the inhabitant of the room with the outside.

The design of the shading device is divided into two steps. In the first, the shadow angles are found by means of superimposing the Shadow Angle Protractor on the Shading Chart (pages VI. 21-22) according to the given orientation. Four horizontal angles, two on each side, and two vertical ones are indicated according to the winter and summer shading lines. The second step is the final design of the device. This is recommended to be adaptable with shadow angles varying between the summer and winter ones. Whenever fixed devices have to be used, the summer angles must be adopted. A further recommendation that is made here is the maximum detachment of the device from the building. The objective behind this is to minimize the transfer to the building of any heat absorbed by the device.

The next two decisions handled by Systematic C are on the construction and type of glazing. Multi glazing, which is recommended for the construction, can only be decided upon after consideration of the economical implications. Similar considerations have to be made when deciding on the type of glazing. The Glazing Chart (page VI.23), which evaluates several types by their performance in the exchange of radiative heat, can be used in this decision whenever a variety of glazing types are available and economically viable. The recommendation in this case is to use a low transfer level glazing. It is of interest at this

point to indicate that the Glazing Chart, the use of which lessens the radiative heat transfer to the internal environment, is partly similar in function to the shading device. The difference, however, is that a shading device can obstruct radiation discriminately. It can be said, therefore, that by effective use of the shading device, a designer can be less dependent on unusual types of glass.

The use of the model in a design problem is illustrated graphically at the end of this chapter in Figs. VI. 4-8.

D. Further Thermal Control of the Building

The two charts which form this part are the Complementary Thermal Requirements Chart and the Natural Ventilation Chart (pages VI. 24-25). The function of these charts differ from that of the rest of the model, since they do not provide a systematic generation of a particular design parameter. Instead, they serve as a guide for the designer, indicating the kind of thermal environment which is likely to be created by a building designed with the help of the model. They therefore help to show the kind of thermal remedies which would possibly be needed at different hours of the day in different parts of the year.

When related to the possible time of use of a space, e.g. bedroom 10 p.m. - 10 a.m., it would be possible to specify the remedial thermal requirements of the room in terms of type, i.e. cooling or heating, number of hours each day and part of the year.

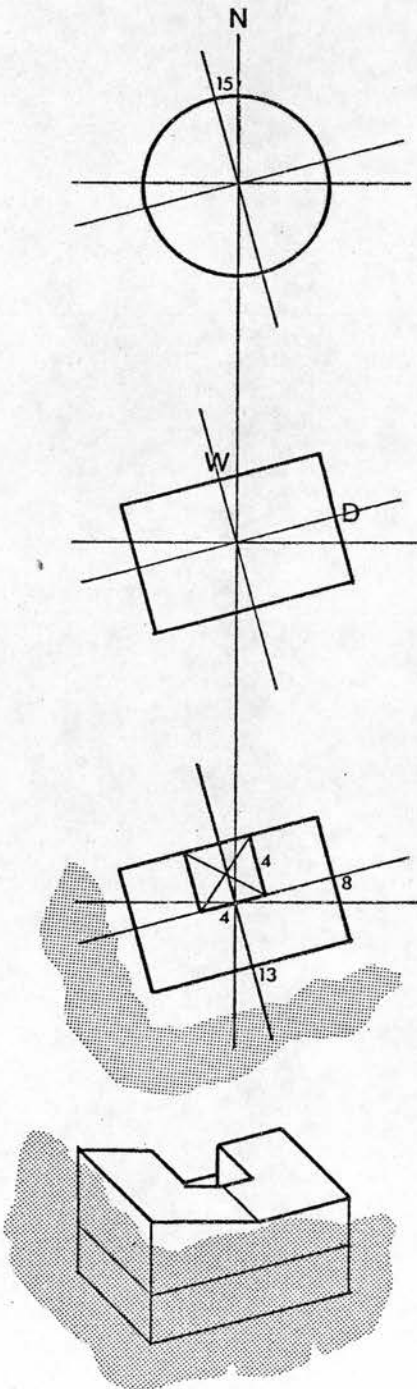
The Natural Ventilation Chart indicates the times of the day natural ventilation can be provided in different months of the year. It will be seen that during winter months natural ventilation is not recommended since non-treated external air is of temperatures which are less than comfortable. This means that any ventilation provided for non-thermal reasons during such parts of the year is thermally undesirable.

The function of these charts can therefore be termed as an informative one, as opposed to the generative character of that of the previous parts of the model.

Constraints

- 1 - Floor Area = 200 ± Sq. m.
2 - Max. Height = 2 Storeys

Process



Chart/Index

Recommended axial orientation	Orientation Index
$\frac{W}{D} = \frac{D\text{-Orient}}{W\text{-Orient}}$ $= \frac{50}{32} = \frac{12.5}{8}$ <p>Plan area = 100 ∴ If D=8 W=13</p>	Plan Proportion Index
4 x 4 m courtyard	Systematic A.1
shading of elements of high insolation values	Insolation Index
Part of roof tilted at 15° towards N.75.E to receive 40% less insolation	Insolation Index

Fig. VI.4

The application of the Orientation and Insolation Indices in the Generative Process

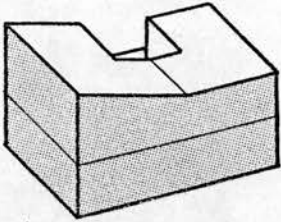
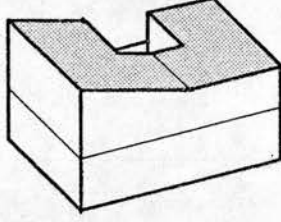
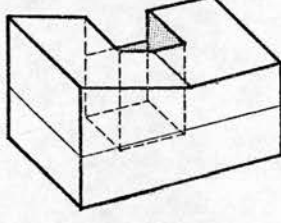
Surface		Colour	Ref.	Logic
Inc.	Az.			
	Exterior Walls	Light Cream	60%	Thermal Economical
	90	N75E		
	90	S15E		
	90	S75W		
	90	N15W		
	Roof	White Portland	60%	Thermal Technological
	0	-		
	15	N75E		
	Court Yard	Medium/Dark Colours	40%	Visual
	90	N75E		
	90	S75W		
	90	N15W		

Fig.VI.5

The decision on the external colour and the use of the Reflectivity Chart

ELEMENT			COLOUR	R + C	R	C
InclinationAzimuth			REFLECTIVITY %	CATEGORY	VALUE	VALUE
EXTERNAL WALLS	90	N.75.E	60	D	1	250
	90	S.15.E	60	C	1.10	280
	90	S.75.W	60	C	1.10	280
	90	N.15.W	60	E	0.85	215
ROOF	0	-	60	A	1.3	330
	15	N.75.E	60	A	1.3	330
C.Y. WALLS	90	N.75.E	40	D	1.15	293
	90	S.75.W	40	C	1.31	335
	90	N.15.W	40	E	0.93	240

Constraints: 1-Masonry material = concrete
2-Insulation material = polystyrene
3-Internal treatment = 2cm gypsum plaster

ELEMENT			Internal Gypsum Plaster cm.	Concrete cm.	Insulation Polystyrene cm.	External Cement Plaster on Lath cm.
InclinationAzimuth						
EXTERNAL WALLS	90	N.75.E	2	9.5	3	2
	90	S.15.E	2	11	3	2
	90	S.75.W	2	11	3	2
	90	N.15.W	2	7.5	2.6	2
ROOF	0	-	2	13	3.5	See Fig (VI.6)
	15	N.75.E	2	13	3.5	
C.Y. WALLS	90	N.75.E	2	12	3.7	2
	90	S.75.W	2	12	3.7	2
	90	N.15.W	2	8	2.9	2

Tables (VI.1) The generation of the R and C Values and their interpretation to building materials by the use of the R and C Values Index, R and C Values Index range and R and C Values Charts.

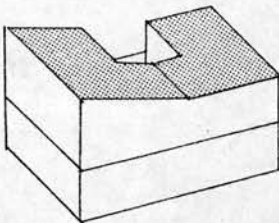
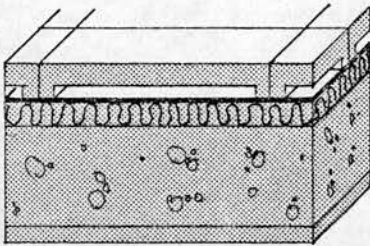
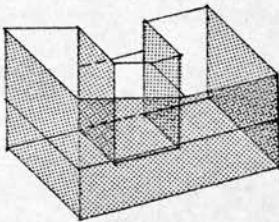
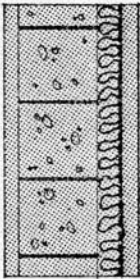
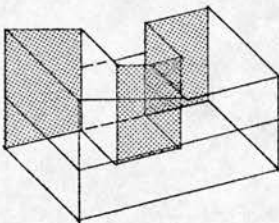
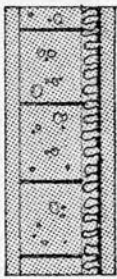
ELEMENT	CONSTRUCTION	cm	
		2 13 3.5 2 3	Internal Gypsum Plaster Concrete Slab Polystyrene. Water-proofing Membrane Air Cavity White Portland Concrete Slab
		2 10 3 2	Internal Gypsum Plaster Concrete Blocks Polystyrene Metal Lath Cement Plaster
		2 8 2.75 2	Internal Gypsum Plaster Concrete Blocks Polystyrene Metal Lath Cement Plaster

Fig.VI.6

The interpretation of the specifications generated in Tables VI.1 into elemental constructions.

Only two types of constructions are specified for vertical elements for techno-economical reasons

Decisions on the courtyard walls of N.75°E and S.75°W were made in view of the fact that they are sheltered by the courtyard.

Constraints

Type of glass: _____ Float Glass

Recommendation

Source

Type of Glazing: _____ Double Glazing _____ Systematic C

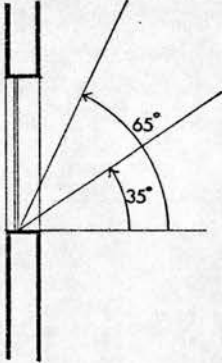
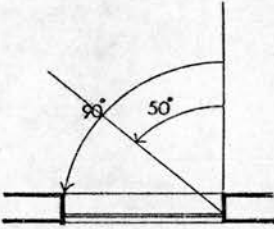
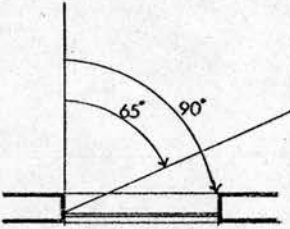
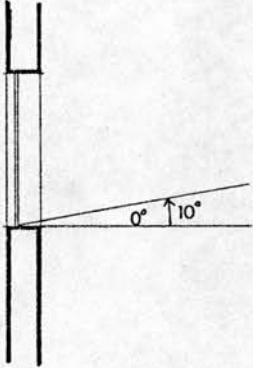
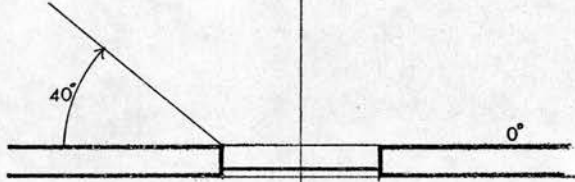
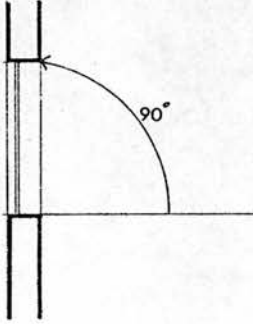
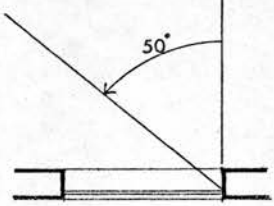
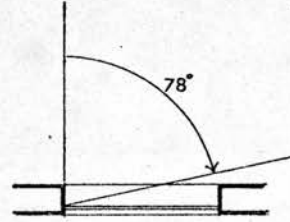
Orientation	Vertical shadow angles	Horizontal shadow angles	
		Left	Right
S.15°E			
S.75°W			
N.15°W			

Fig. VI.7 The decision on the shadow angles by the use of the shadow angle protractor of the Shading Chart

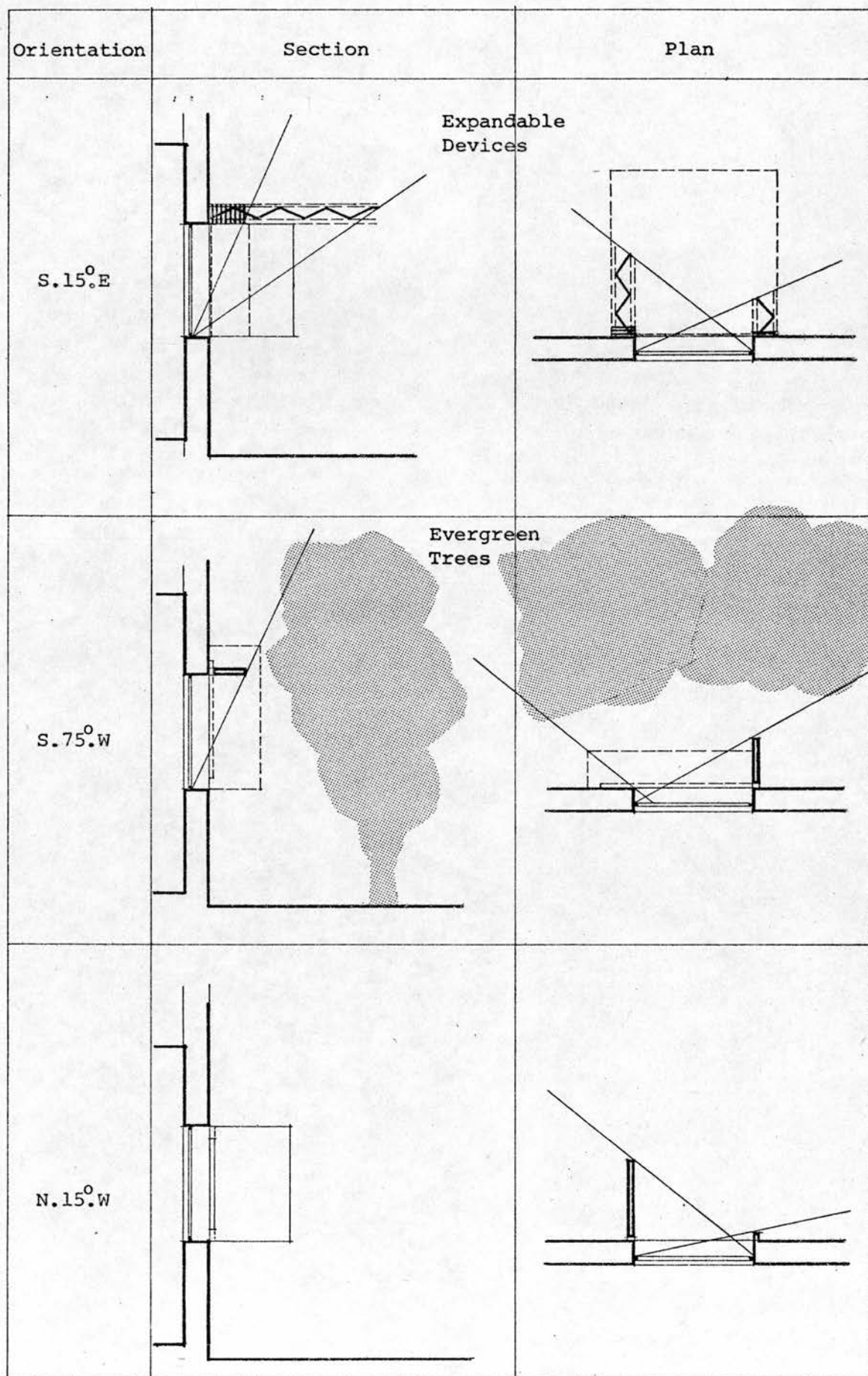


Fig. VI.8

The design of the shading devices in accordance with the shadow angles

3. Concluding Remarks

Limited by time, research can follow one of two paths, to tackle one part of the problem intensively and produce highly accurate solutions for it, or to aim at comprehensibility by attempting to solve all parts and produce a satisfactory solution for the whole problem. Since a bad decision on one parameter can nullify the effect of a good one on another, e.g. construction of wall versus shading of windows, an approach which is aimed at the designer has to take into consideration all parameters of the thermal form.

On the other hand, the generation of the thermal form of the building can only have a practical meaning when considered within that of the total architectural form. Conventionally, the intuitive approach to the design process makes the generation of the component forms coincidental and unclear. Its main advantage to the designer is in overcoming the ⁿidefiniteness in his mind of the _hrelationships between the individual component forms and their determinants. In order to paint a clearer picture and work towards a more rational approach one would have to analyse all component forms and establish a network of interactions between the determinants of each of the design parameters. Equally valuable and complementary to this would be a relative evaluation of these determinants. In this respect this thesis only goes so far as defining the

component forms and relating the thermal form to the total architectural form.

Concerned with the thermal form, the thesis starts by establishing guidelines for an approach to thermal design. These are used in the intermediate chapters as bases for developing a generative model. The last chapter constructs the model, discusses its implications and demonstrates its application to a design problem. Although an evaluation of the model can best be made by an assessment of comfort in an internal thermal environment of a building designed by its application, a study of the model and the approach and procedure that led to it can highlight its drawbacks.

To develop the various parts of the model, the thesis follows a flexible approach. Dealing with the various parts of the thermal design problem, the approach is dictated by the amount of established research on the particular part and the extent of its relevance to the generative character of the thesis. The general aim of the thesis is to find suitable generative criteria, whether by adopting and processing arguments developed by other researchers or by developing its own. An underlying objective which is clear throughout the thesis is the systematization of the generation. By a study of the model and its development it is possible to describe it, in the context of the thermal form, as comprehensive. It is,

however, less than complete and has some drawbacks which are worth noting. They are mainly reflections of the considerable lack of information in some parts of the field.

Two of the major problems that are largely unresolved are the evaluation of the climate of the site and the prediction of the microclimatic implications of an envisaged building. The first stems from the fact that climatic data is supplied by meteorological stations for the benefit of many fields including building design. This information does not reflect the local variations of the properties of the climatic elements. Whereas air temperature, humidity and wind can vary between localities, they can be assumed to have uniform properties over a homogeneous locality. But the effect of solar radiation can vary between building sites since it is governed by the geometrical setting of the surrounding masses of buildings or trees. The relationship between the geometrical setting of elements or buildings and their insolation is a field of major importance in climatic design since, as can be seen from the intermediate part of the thesis, it can influence the generation of the geometry and orientation of the building, the R and C values of the single element and the geometrical characteristics of the window and its shading device. Lack of information on this subject is the reason why some assumptions had to be made in calculating the insolation of elements. It is also

the cause behind the fact that, without making some simplifying assumptions, the model is unsuitable for geometrical forms with elements that shade one another.

Research concerned with the relationship between a composition of elements and the sun, and its effect on the insolation of the elements is being carried out in the Department of Architecture of the University of Edinburgh. Unless such efforts are complete an approach like this thesis has to build on some assumptions and therefore can not achieve its objectives as accurately as desired.

APPENDICES

PRINCIPAL SYMBOLS USED

n	Angle between solar rays and normal to plane
β	Inclination of the plane
α	Solar altitude
A	wall-solar azimuth
A_p	Plane azimuth measured from south
A_s	Solar azimuth measured from south
ϕ	The geographical latitude
δ	The solar declination
H	The hour angle
β_s	Surface-sky angle factor
I	Intensity of direct solar radiation incident on plane
I_{RF}	Ground reflected solar radiation falling on plane
I_{DF}	Diffuse solar radiation falling on plane
I_N	Intensity of direct normal solar radiation
I_{GG}	Intensity of global radiation falling on ground

I_m	Maximum intensity of incident solar radiation
I_{Global}	Intensity of global radiation falling on plane
DI_{RF}	Daily total over-21 reflected radiation received by plane
DI_{DF}	Daily total over-21 diffuse radiation received by plane
DI	Daily total over-21 direct radiation received by plane
YI	Yearly total over-21 solar radiation received by plane
IN	Insolation number of plane
M	The solar constant
N	The extinction coefficient
K	Diffuse solar radiation factor
r	Reflectance factor - %
J_r	Factor for computing the thermal resistance of elements
J_c	Factor for computing the thermal capacity of elements
a	Absorptivity of surface to solar radiation
R	Thermal resistance of an element
R_w	Thermal resistance of walls
R_r	Thermal resistance of roofs

C	Thermal capacity of an element
Cw	Thermal capacity of walls
Cr	Thermal capacity of roofs
To	Maximum outside air temperature
to	Minimum outside air temperature
Ti	Maximum inside air temperature
Wa	Weight of the external wall per unit external surface area
Wb	Average weight of structure per unit external surface area
p	Density of material
c	Specific heat of material
K	Thermal conductivity of material
k	Thermal conductance of element
d	Thickness of element
W	Width of a rectangular plan
D	Depth of a rectangular plan
Ins	Total over-21 insolation of walls of building
X	Insolation number of W-sides of building
Y	Insolation number of D-sides of building

APPENDIX I

The Geometry of the Celestial Sphere

APPENDIX II

The Geometry of the Elemental Plane in
Relation to the Sun

APPENDIX III

Determinants of the Intensity of Incident
Solar Radiation

APPENDIX IV

The Thermal Comfort of Man in a Hot Dry
Climate

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2. Heat Regulatory Mechanisms
 - 2.1 Blood Circulatory Mechanisms
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3. The Skin-Environment Heat Exchange Mechanism
 - 3.1 The Evaporative Heat Exchange
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The Thermal Mechanism of the Building and
Its Determinants

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 - 1.1 The Thermal Exchange Between the External Surface and the External Environment
 - 1.1.1 Convective
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 - 1.2 The Thermal Exchange Between the External Surface and the Material Layers of the Element
 - 1.2.1 The Thermal Capacity
The Significance of the Amount of the Thermal Capacity
 - 1.2.2 The Thermal Resistance
Determinants of the Material's Thermal Resistivity
 - 1.2.3 The R-C Compositional Relationship
Adaptable Insulation
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 - 2.1 The Radiative Transmission and Exchange
 - 2.2 The Conductive Exchange
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 - 3.1 The Mechanism of Natural Ventilation
 - 3.1.1 Thermally Induced Ventilation
 - 3.1.2 Wind Induced Ventilation

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Traditional Architecture of Baghdad

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2. The Courtyard House of Baghdad
 - 2.1 The Spacial Concept
 - 2.2 The Thermal Logic of the Geometry
 - 2.2.1 Criticality of the Courtyard Geometry
 - 2.2.2 Thermal Exchange Mechanism

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Insolation of the Courtyard

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Climate of Baghdad

1. The Geographical Setting of the City and Its Region
2. Climatic Regional Evaluation
3. Climate of the City of Baghdad
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 - 3.2 Humidity
 - 3.3 Clouds
 - 3.4 Rain
 - 3.5 Radiation
 - 3.6 Storms and Dust Storms
 - 3.7 Wind

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APPENDIX II

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2 {Relation to the Sun	
3 {The Use of the Shadow Angle Protractor in	
4 {Predicting the Exposure Times of Elemental	
4 {Planes	

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7	Two Sections in a Courtyard House
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11	The Criticality of the Courtyards Geometry
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(Contd.)

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6	Wind Frequency and Prevailing Wind Direction
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9	Monthly Mean Maximum and Minimum Relative Humidity
10	Monthly Mean Daily Total Cloud
11	Monthly Mean Daily Total Rainfall

APPENDIX I

The Geometry of the Celestial Sphere

The angles in Fig. AI.1 are related by spherical trigonometry in the following equations :

$$i) \quad \sin \alpha = \sin \varphi \sin \delta + \cos \varphi \cos \delta \cos H$$

$$ii) \quad \frac{\sin A_s}{\cos \delta} = \frac{\sin H}{\cos \alpha}$$

$$iii) \quad \cos A_s \cos \alpha = -\cos \varphi \sin \delta + \sin \varphi \cos \delta \cos H$$

Where

A_s is measured from the south

φ represents a north latitude

$H = 15^\circ \times \text{No. of hours from solar noon}$

δ has the monthly values given in table AIII.1

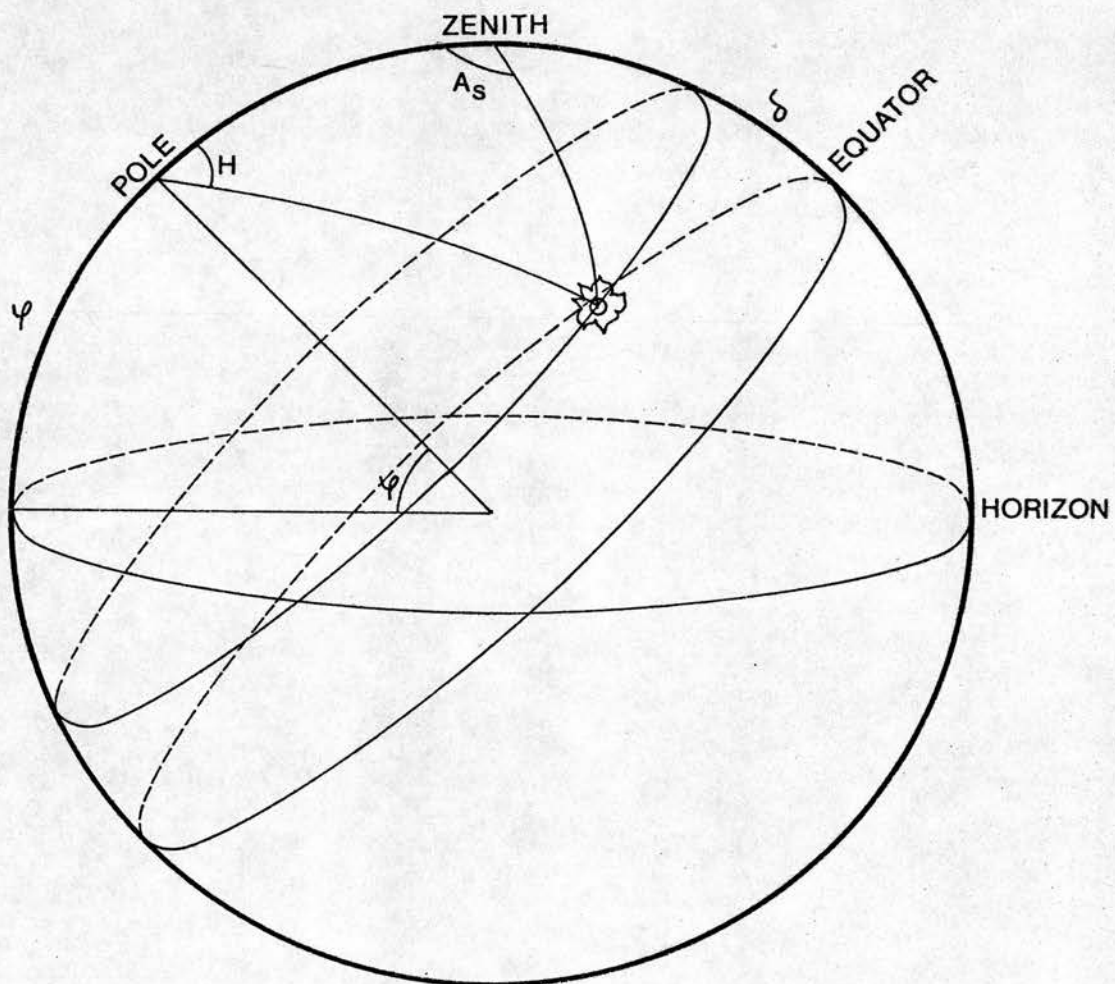


Fig. A1.1

The Celestial Sphere

APPENDIX II

The Geometry of the Elemental Plane in Relation to the Sun

In Fig. A II.1

O is the centre of a celestial sphere
 Plane MPN is the plane of an inclined wall
 Circle MPN is the intersection of the plane and the sphere
 B is the inclination of plane to horizontal
 OP is the line of greatest inclination
 Q A point on the great circle MPN
 P', Q' Projections of points P, Q on horizontal

Consider a plane parallel to horizontal, passing
 through Q and meeting PP' and OP in R and S
 respectively.

Let S' be a projection of S on the horizontal

$$\angle PSR = B$$

$\triangle SRQ$ is similar to $\triangle OP'Z$ and $\triangle S'P'Q'$

$$\therefore \angle RSQ = \angle POZ = \angle P'S'Q' = 90^\circ \quad \left(\text{since } OZ \text{ is } \perp \text{ to } \begin{matrix} \triangle LE \\ OP' \end{matrix} \right)$$

$$i) \quad PS = \frac{SR}{\cos \beta} = \frac{S'P'}{\cos \beta} = \frac{OP' - OS'}{\cos \beta} = \frac{r \cos \beta - r \cos \alpha \cos \gamma}{\cos \beta}$$

(Since $OS' = OQ' \cos \gamma = r \cos \alpha \cos \gamma$, r is the radius)

Also

$$ii) \quad PS = \frac{RP}{\sin \beta} = \frac{PP' - RP'}{\sin \beta} = \frac{PP' - QQ'}{\sin \beta} = \frac{r \sin \beta - r \sin \alpha}{\sin \beta}$$

From i) and ii)

$$iii) \quad \cos \gamma = \tan \alpha \cot \beta$$

In Fig. A II.2

Let A_p be azimuth of plan
 A_q be azimuth of point Q } Measured
 from south

If P and Q are on one side of the North-South axis :

$$\therefore 180 \pm \gamma = A_p + A_q$$

$$\text{iv) } \gamma = \begin{matrix} + \\ - \end{matrix} [180 - (A_p + A_q)]$$

Otherwise

$$\text{v) } \gamma = 180 \pm (A_p - A_q)$$

From iii, iv, v, :

$$-\cos(A_p + A_q) = \tan \alpha \cot \beta$$

$$-\cos A_p \cos A_q + \sin A_p \sin A_q = \tan \alpha \cot \beta$$

$$\text{vi) } -\cos A_p \cos A_q \cos \alpha + \sin A_p \sin A_q \cos \alpha = \sin \alpha \cot \beta$$

Taking "Q" as a point of intersection of the circle "MPN"

and the sun path, Fig. A II.3

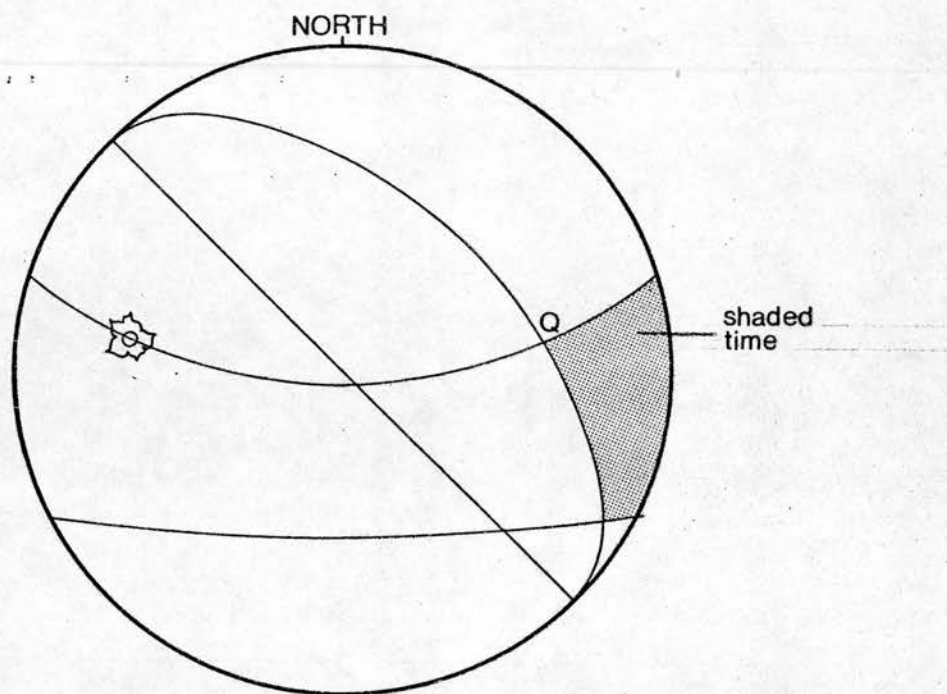


Fig. AII.3

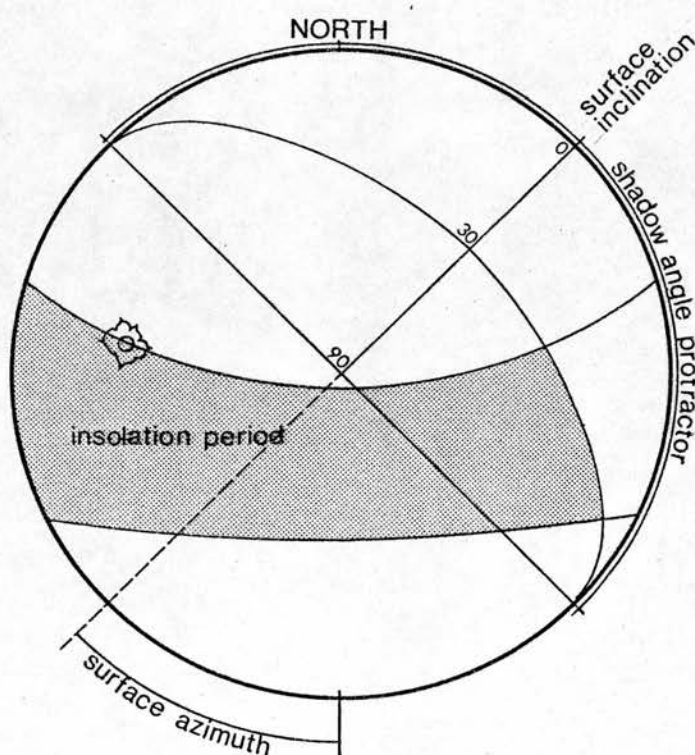


Fig. AII.4

The Use of the Shadow Angle Protractor
in Predicting the Exposure Times of
the Elemental Planes

From equations i, ii and iii in Appendix I,

$$\cos A_q \cos \alpha = -\cos \varphi \sin \delta + \sin \varphi \cos \delta \cos H$$

$$\sin A_q \cos \alpha = \cos \delta \sin H$$

$$\sin \alpha = \sin \varphi \sin \delta + \cos \varphi \cos \delta \cos H$$

Substituting in vi

$$\begin{aligned} \text{vii) } \sin H \sin A_p - \cos H [\cos A_p \sin \varphi + \cot \beta \cos \varphi] = \\ \tan \delta [\cot \beta \sin \varphi - \cos A_p \cos \varphi] \end{aligned}$$

Equation vii can be used in computing insolation hours of the day for an inclined surface at a north latitude.

For practical use; the shadow angle protractor (U.N., 1971), although devised for different purposes, can be used by considering the vertical shadow angles as surface inclinations. (See Chapter III).

APPENDIX III

Determinants of the Intensity of Incident Solar Radiation

The intensity of the direct normal solar radiation reaching the earth depends upon :

- A. The solar constant, which varies with the solar activity and the earth's distance from the sun, causing a variation of $\pm 3.5\%$ (Groundwater, 1967). An average value for the solar constant is given as $5048 \text{ kJ.hr}^{-1}.\text{m}^{-2}$
- B. Determined by the solar altitude, the amount of air mass through which the radiation travels has a decisive effect on the amount received at the earth's surface since it determines the effect of the atmospheric extinction, due to absorption by ozone in the upper atmosphere to all wavelengths below 0.288 and most of the ultra violet rays, and by Carbon Dioxide and water vapour of a considerable amount of the infra red rays. Water droplets in the atmosphere generally reflect radiation non-discriminately. Reflected and diffused radiation are also due to dust particles (Rao and Seshadri, 1961; Robinson, 1966)

An atmosphere which was assumed to be characteristic of

Europe and the United States was described by Groundwater (1967) as :

760 mm	Barometric pressure
20 mm	Precipitable water
300 Particles/cm ³ dust	- Summer and Spring
2.8 mm	Ozone

A standard tropical atmosphere has been described by Sharma and Pal (1965). It differs from the above by its precipitable water content of 15 mm and 2.5 mm ozone. Working from the fact that a decrease in an atmospheric element like water vapour is likely to be substituted by an increase in another like dust, the overall depletion of the solar energy was assumed to be constant and an equation was found to calculate the intensity of the radiation reaching the ground

$$I = \frac{A \sin \alpha}{\sin \alpha + B}$$

Where

$$A = 1.842$$

$$B = 0.3135$$

For global application, the Ashrae Guide (1967) uses a more adaptable formula :

i)

$$I = \frac{M}{\text{EXP}(N/\sin \alpha)}$$

Where M is the apparent solar irradiation at
air mass = 0, and N is the extinction
coefficient derived by Threlkeld and Jordan
(Morris and Lawrence, 1969), monthly values
are given in Table A III.1

Date	Declination	Solar Constant M ($\text{kJ} \cdot \text{hr}^{-1} \cdot \text{m}^{-2}$)	Extinction Coefficient N	Diffusivity Factor K
21st Jan	-20	4424	0.142	0.058
Feb	-10.8	4370	0.144	0.060
Mar	0	4273	0.156	0.071
Apr	11.6	4090	0.180	0.097
May	20	3972	0.196	0.121
June	23.45	3918	0.205	0.134
July	20	3907	0.207	0.136
Aug	12.3	3983	0.201	0.122
Sep	0	4144	0.177	0.092
Oct	-10.5	4295	0.160	0.073
Nov	-19.8	4392	0.149	0.063
Dec	-23.45	4435	0.142	0.057

Table A III.1 The Solar Declination, Apparent Solar Irradiation at air mass = 0, Extinction Coefficient and Diffusivity Factor Given for the 21st of Each Month as used by the Ashrae Guide (1967) in calculations for latitudes 24 - 56° North.

Substituting for $\sin \alpha$ from equation i), Appendix I, in equation i), Appendix III

$$i) \quad I = M \text{ EXP } \left[-N / (\sin \varphi \sin \delta + \cos \varphi \cos \delta \cos H) \right]$$

- C. Cloudiness and humidity, which vary with latitude, have an important effect on the geographical distribution of radiation received by the earth. The two elements combined are responsible for the fact that the subtropics receive a maximum amount of radiation. Fig.AIII.1

Generally, hot arid areas have clear skies that are scarcely disturbed by clouds. Their colour can often be intense blue (Miller, 1931 and Thornthwaite, 1958) throughout the long undisturbed overheated summer. A study of the climate of Baghdad in Appendix VIII shows that during the period between 1st of June and the end of September 95% of the days are of clear sky and only 0.08% are cloudy. Excluding the cold period of the year (the period in which the maximum air temperature does not rise to comfort level) one finds that only 4% of the total number of days are cloudy days. This allows for the use of the cloudless state as a design condition.

- D. The effect of the altitude of the site on the intensity

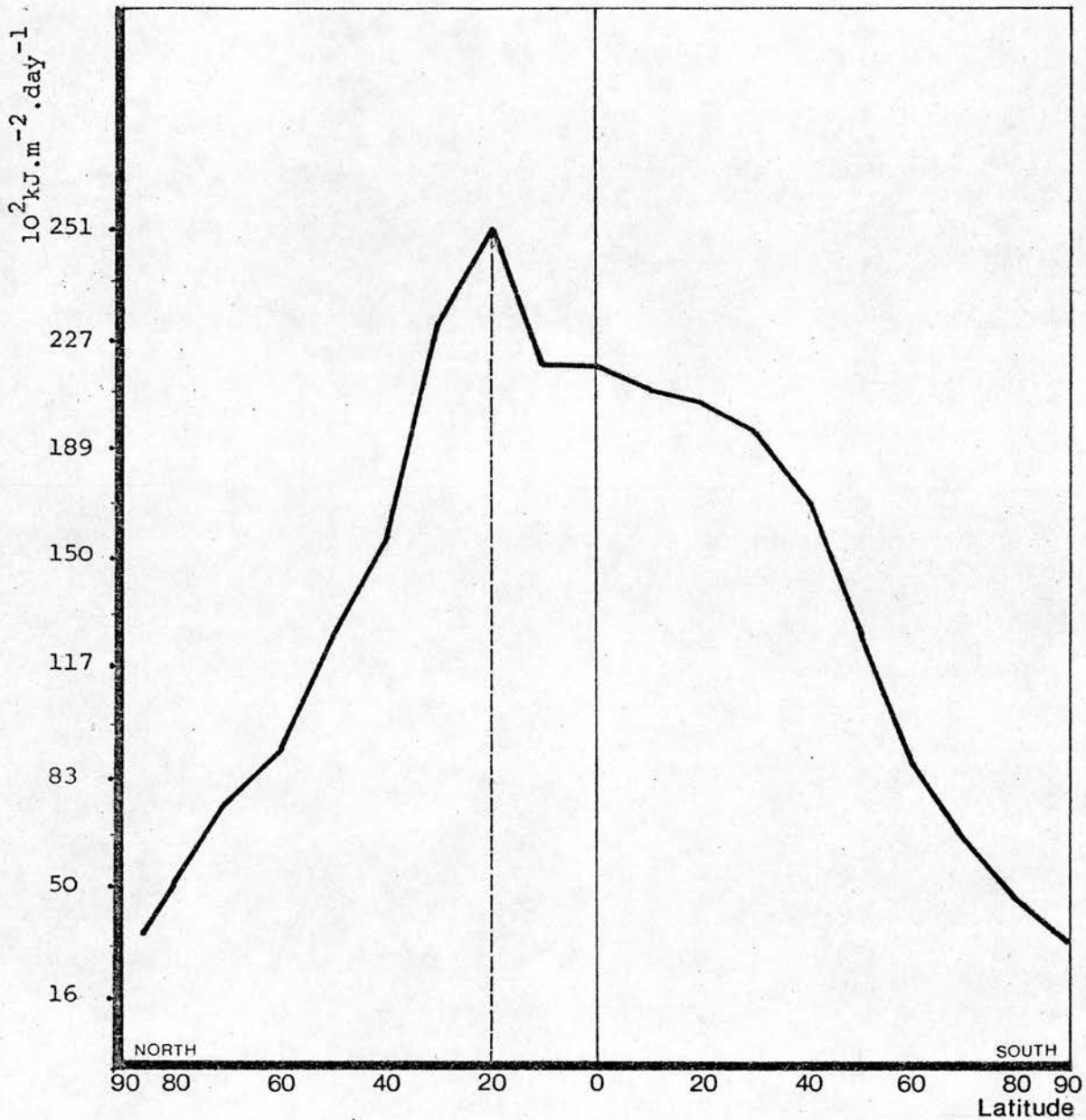


Fig.A III.1

Yearly Average of the Mean Monthly Global Solar Radiation
at 40°E Meridian

After a Table by Givoni (1969)

The Assymetry of the Curve can be Attributed to the Uneven
Distribution of Land and Sea, Thus Humidity, North and
South of the Equator

of radiation received can be seen from Table A III.2, which shows measurements at different heights above sea level.

HEIGHT	M	MEAN ENERGY LANGLEYS/SEC
Sea Level	0	1.40
	1580	1.59
	3400	1.63
	4350	1.72
Balloon	19500	1.89

Table A III.2

(Robinson, 1966)

The values in the table show that only in spectacular changes of height, which can only occur in few mountainous regions, does the radiation received vary with enough significance to justify its consideration for the purpose of this work.

APPENDIX IV

The Thermal Comfort of Man in a Hot Dry Climate

The subjective assessment of the human being of the level of comfort of his thermal environment can be interpreted in physiological terms. Thermally comfortable conditions are those under which the heat regulatory mechanisms of the body are at minimal activity. These mechanisms have the function of controlling the rate of loss of metabolic heat to the environment by radiation, convection and evaporation.

1. The Heat Produced by Metabolism

The metabolic heat production varies with the activity. The following table gives an estimate of the variation of metabolic rate with activity (Turner, 1969).

Activity	Metabolic Rate (Watts)
Base	85
Sedentary	115
Light	205
Normal	250
Heavy	310

Metabolism varies also with the size of the individual and his body build, sex, age, health, nutrition and climate. These factors impose a difference in metabolic rate between individuals, but for a particular individual the variation is mainly due to the activity.

2. Heat Regulatory Mechanisms

These mechanisms have the function of regulating the loss of heat by the body to its environment. They control the rate of exchange of heat between the body, its skin and eventually the environment.

2.1 Blood Circulatory Mechanisms

Other than by simple conduction, heat transfer between the internal part of the body and the skin is a function of the blood circulation. The extensive network of blood vessels existing beneath the skin and feeding the tissues with blood, bring it to considerable proximity of the environment and consequently the heat carried by the blood can be lost to the surroundings through the skin.

The body, by a sophisticated system of control, can regulate the amount of blood that reaches the peripheral parts, and consequently the amount of heat loss. By vasodilatation, which is a process of expansion of peripheral blood vessels and pumping up to 50 or 60% of the total blood to them, a promotion of heat loss occurs. This mechanism takes place in conditions of heat stress. Vasoconstriction, on the other hand, has the opposite function and its mechanism is the reverse to that of vasodilatation.

Bruce (1960) registers a more detailed account of the above mentioned processes and mentions that the body content of blood increases in hot environments and decreases in cold ones producing general vasodilatation and vasoconstriction.

2.2 Perspiration

This is a cooling process dependent on evaporative heat loss from the body, which rate is controlled by the amount of moisture in the skin.

Body perspiration is of two kinds, insensible and sensible. Insensible perspiration is the continual process of loss of water from the skin and lungs when the body is in a moderate thermal environment. Sensible perspiration occurs when the body is under heat stress and it involves the secretion of moisture by means of the sweat glands forming palpable sweat (Yaglou, 1953), which is mainly a weak solution of sodium chloride and water.

The use of sensible perspiration as a cooling mechanism can be explained by the fact that the rate of evaporative heat loss from the skin to its environment is a function of the difference in their vapour pressures. A body which is under heat stress in a humid environment would have to secrete an amount of sweat which would cause the elevation of the vapour pressure of the skin, and therefore the skin-air pressure gradient, to a level which will ensure a certain rate of heat loss by the body.

The above described phenomenon has been used by the scientists to develop indices for the evaluation of the thermal conditions in which a body exists, by calculating its sweat rate (Givoni, 1969).

2.3 Other Regulatory Means

In addition to the mechanisms described above, there is one more involuntary mechanism which comes to use when the body is under a cooling stress, and that is shivering. This is a series of muscular movements which occur when the maximum amount of vasoconstriction fails to moderate the rate of heat loss. By shivering an amount of heat is produced to make up for the excessive heat loss to the environment.

Voluntary responses made by the human being help in supplementing the mechanisms described above. Such responses in a hot environment can take the form of shading the body from the sun, reducing the amount of clothes worn and reducing the amount of physical activity.

Clothing has an important effect on the heat exchange mechanism between the body and its environment. Much of

the differences in the requirements for comfort between men and women have been attributed to the variations in clothing (Bruce, 1960). It restricts the heat exchange by all three means; convection, radiation and evaporation and the body becomes less sensitive to changes in the temperature and speed of the air. When the air temperature and the MRT are less than 35°C , clothes limit heat loss by convection and radiation, and thus have a warming effect. When they are more than 35°C clothes limit heat gain by convection and radiation but restrict heat loss by evaporation by increasing the humidity over the skin and reducing the air velocity near it.

3. The Skin-Environment Heat Exchange Mechanism

In a thermal environment, the parameters which determine the level of comfort are :

environment	A. Air temperature
	B. Temperatures of surrounding surfaces
	C. Air speed
	D. Atmospheric vapour pressure
man	E. Skin temperature
	F. Skin vapour pressure
	G. Body heat production
	H. Body surface area, postural attitudes and clothing.

The human body loses heat to the environment by convection, evaporation and radiation and the rate of heat exchange by any of these three means vary according to the ambient conditions at the time. For a seated comfortable person in conditions of uniform equal temperatures of air surroundings and a minimum air movement of 0.083 - 0.117 m/sec, the heat loss from the body through convection and radiation are roughly equal and account for approximately 2/5 of the total each. When the body starts to move or with air motion increase, the loss through convection greatly exceeds the loss through radiation and the dry bulb air temperature becomes much more important than the mean radiant temperature in determining comfort (Olgyay, 1963).

It is possible to explain the heat exchange process by considering a human body which is put in an environment which is initially of a lower temperature than his; the body in this case would be losing heat to its environment by convection and radiation. As the dry-bulb temperature of the environment increases it approaches the temperature of the body and consequently rate of heat loss from the body to the environment by convection and radiation is reduced, until a sensation of heat discomfort occurs. A sedentary person with light work can generally comfortably tolerate a dry-bulb temperature of up to 29°C, at which stage the body senses thermal discomfort and consequently the sweat

glands become active and heat loss by evaporation takes a more major role (Drysdale, 1961).

3.1 The Evaporative Heat Exchange

For a wide range of humidity conditions the moisture evaporated from the non-wet skin is readily absorbed by the atmosphere, and the significance of the humidity in relation to comfort only becomes of value when the sweat glands become active and palpable sweat appears.

The effect of humidity level on the comfort of a human being is due to its limitation to sweat evaporation from the skin and hence the efficiency of evaporative cooling of the skin by sweat. The differences between the vapour pressures of the skin and the air determine the air's evaporative capacity. Thus, from the physiological point of view the vapour pressure is the most convenient way of expressing the water content of the atmosphere. Vapour pressure of the skin is dependent upon its temperature and varies from 37 mm Hg for a comfortable skin temperature of 33°C to 42 mm Hg for moderate heat conditions of 35°C skin temperature and up to 47 mm Hg for severe heat skin temperature of 37°C. Givoni (1969) gives the value of 42 mm Hg as a suitable working value for the

skin vapour pressure.

Drying effect of low humidity air may cause dryness of the lips and the mucous membranes of the nose and throat. Dryness of the lips and nose occurred when tests were made with air at 12% to 15% RH. This effect was proved to occur whenever the atmospheric vapour pressure is below 10.16 mm Hg (Bruce, 1960). It has been suggested elsewhere (Givoni, 1969), that humidification is advisable for a vapour pressure below 8 mm Hg. By taking this as a comfort boundary on the basis that discomfort above this value is slight or unnoticeable, one can set limits for comfortable humidity in the atmosphere.

The effect of overhumidification of the atmosphere on comfort is of obvious importance since it limits the evaporative cooling of the skin. The Olgyay charts (Olgyay, 1963) show that vapour pressure above 15 mm Hg is undesirable, but can be tolerated by providing an air movement equivalent to 0.45 m/sec. for every additional 1 mm Hg of vapour pressure. As will be found later, air movement above 1 m/sec. is undesirable. As a conclusion to the above, dehumidification is necessary for vapour pressures above 15 mm Hg in still air and 17 mm Hg with air movement.

The revised ASHRAE Comfort Chart, (1967), sets boundaries for comfort as slightly cool at 22°C and slightly warm at 28°C the optimum being at 25°C . It can be seen from the chart that the relative humidity has no effect on the feeling of comfort at 22°C dry bulb temperature, whereas at 25°C relative humidity above 70% produces a slight feeling of warmth of approximately 0.6°C per 20% RH rise. At 28°C , the upper limit of the comfort area, the effect of humidity is even more pronounced. It starts above 52% giving a warming effect equivalent to the effect of 0.8°C rise in dry-bulb temperature for a 20% RH rise. Equivalent value to humidity is given by Givoni (1969) in his Building Bioclimatic Chart.

The relative humidity in a hot-dry climate fluctuates considerably with air temperature between a minimum in the afternoon and a maximum at night. The vapour pressure element in the climate of Baghdad fluctuates annually between $5\frac{1}{2}$ mm Hg in December and $11\frac{1}{2}$ mm Hg in July. (See Appendix VIII).

Considering the above facts and the point discussed previously that vapour pressure above 17 mm Hg requires dehumidification; it can be stated that generally speaking, at no time of the year does a hot dry climate require dehumidification. For comfortable humidity in these climates, the only aspect that shows a need for an adjustment is the drying

effect, which sets a limit of minimum comfortable humidity.

3.2 The Radiative Heat Exchange

Radiation affects the thermal comfort of human beings when incident on the skin. Various wave lengths of radiation penetrate the skin differently and produce a different warming effect. Early experiments by Oppel and Hardy (Bedford, 1964) employed three kinds of radiation:

- A. Visible of 0.4 to 0.7 microns
- B. Penetrating infrared 0.8 to 3 microns
- C. Non-penetrating infrared radiation of wavelengths longer than 3 microns.

They found that when the skin of the forehead was irradiated for 3 seconds, the minimum amount of radiation which was needed to evoke a sensation of warmth was in the ratio 3:2:1 respectively of the different wavelengths, i.e. the more penetrating the rays, the less sensitive the skin is to them.

Shorter wavelength radiation penetrates the skin, whereas radiation of a wavelength over 3 microns has no appreciable penetration. Givoni (1969) reports a study which suggested

that the skin absorptivity to radiation at 3 - 20 microns is nearly 100%. The wavelength of the radiation emitted by a wall is of the long range, and thus is about three times as effective as the visible radiation and twice as effective as the infra-red of 0.8 to 3 microns wavelength in producing a warming effect on people.

When comfortable conditions are assessed by means of the dry-bulb temperature only, it is assumed that the walls, the floor and the ceiling are of the same temperature as the air. Experiments were done (Bruce, 1960) on the effect of three walls in a room of a cooler temperature than the air temperature. An experimental room with a basic uniform air and walls temperature of 21°C was considered. It was found that a reduction of walls temperature to 18.3°C was compensated for by an elevation of air temperature of 0.7°C , i.e. approximately 0.25°C air temperature rise per 1°C wall temperature reduction. A wall temperature reduction to 7.2°C was compensated for by a rise of the air temperature to 26°C , i.e. 0.35°C air temperature rise per 1°C wall temperature reduction.

These findings, Bruce reports, are in correlation with calculations on the operative temperature, which states that the temperature of the six surrounding surfaces have an equal

effect on the thermal environment as the air dry-bulb temperature. It can be expressed by :

$$t_o = \frac{6t_a + t_{w1} + t_{w2} + \text{-----} + t_{w6}}{12}$$

where: t_o = operative temp. t_a = dry-bulb air temperature
 t_w = temperature of one internal surface.

By studying the formula for the operative temperature, we can see that the effect of the temperature of the six surfaces on the thermal sensation is equivalent to the effect of air temperature, and a change in the air temperature can be compensated by equivalent change in the mean temperature of the six surfaces i.e. :

$$t_o = \frac{t_a + t_w}{2}$$

where t_w is the mean internal surface temperature.

t_w is sometimes expressed as the mean radiant temperature MRT (Van Straaten, 1967).

An increase in the velocity of air reduces the effect of the MRT relative to the air temperature.

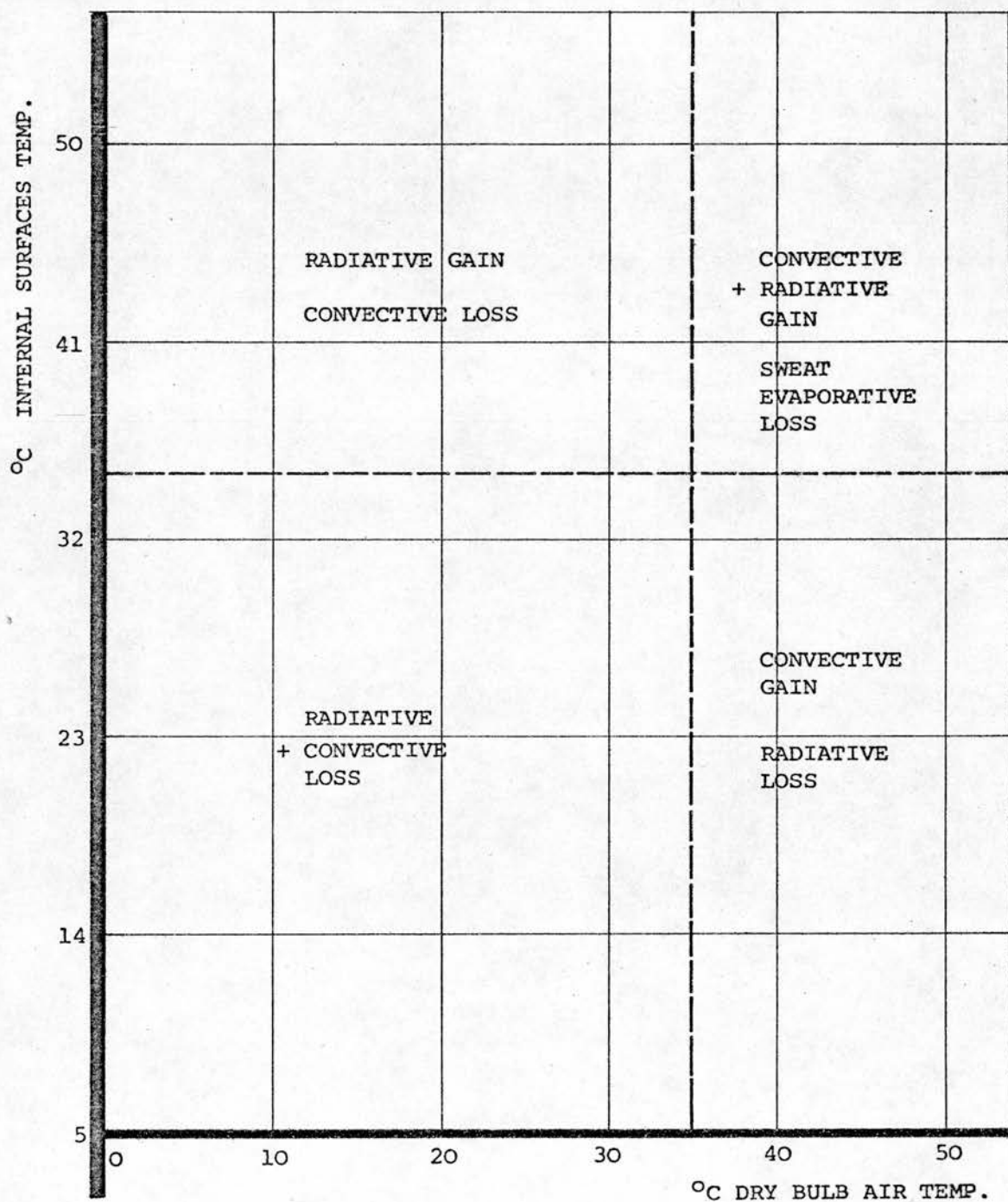


Fig. A IV.1

The effect of the variation of the air temp. and the internal surfaces temp. on the heat exchange between man and the internal environment.

In a climate of hot-dry nature, in order to maintain thermal comfort inside the building, its doors and windows must be closed during the summer daytime hours (Chapter IV). It would be a fair assumption therefore that the temperature of the air inside the building will follow those of the inside surfaces.

3.3 The Convective Heat Exchange

When comfortable, at rest, in uniform and equal air and surrounding temperatures and still air (0.125 - 0.166 m/sec.) the body loses heat almost equally through radiation and convection. When the body moves or when air gains speed, convective loss increases whereas radiative loss decreases.

At air temperature higher than those of the skin, higher air velocities can have contrasting effects in affecting the heat exchange. It would promote convective heat gain by the body at the same time as it encourages evaporative heat loss.

The cooling effect of the wind has been discussed by many scientists. Richards (1959) states that at high temperatures the cooling effect for an air speed of 1 m/sec. is equivalent to a drop in dry-bulb temperature by about 1.67°C in still

air. Bruce (1960) discusses that around 18.3 to 21°C air temperature and 0 to 0.25 m/sec. air velocity, every 0.13 m/sec. change in air velocity compensates for 1°C change in dry-bulb temperature. He also mentions another investigator's findings that for a rise in air temperature above 21°C at 0.07 m/sec. velocity, 1.22°C compensated for the first 0.07 m/sec. rise, 0.8°C for the second and 0.5°C for the third, i.e. 23.5°C for 0.31 m/sec.

Olgyay's Bioclimatic Chart (Olgyay, 1963) indicates the upper limit of the comfort zone at 28°C dry-bulb air temperature and air velocity of 0.1 - 0.16 m/sec. Assuming 30% RH one can set the following table :

<u>Rise in air velocity</u> <u>m/sec</u>	<u>Compensated temp. rise</u> <u>°C above 28°C</u>
0.13 - 0.5	1.28
0.5 -- 1.0	0.94
1.0 - 1.5	0.61
1.5 - 2	0.50

From the equivalent temperature chart (Bruce, 1960), one can see that an activation of wind to a speed of 0.5 m/sec. at around 28°C air temperature will produce a cooling effect enough to counterbalance a rise in temperature of 1.4°C.

An ASHRAE table (1967), sets values for high dry-bulb temperatures that can be tolerated in daily life by acclimatized men, with summer clothing and light sedentary activities :

RH	0.07 - 0.13 m/sec Dry-bulb temp	30.5	91.5	(85°F ET)
40	37.8	38.4	39.5	
20	42.4	43	43	

The table shows the relatively small effect an escalation of wind speed has in high dry-bulb temperatures and relative humidities.

Although air movement helps convective and evaporative heat loss, there are limits for wind speed above which the wind becomes annoying to the occupants. Still air and air velocities of up to 0.5 m/sec. are agreed upon to be pleasant or unnoticed. Velocities between 0.5 - 1 m/sec are considered generally pleasant and acceptable; and 1 - 1.5 m/sec as slightly draughtly to annoyingly draughtly (Givoni, 1969 and Olgyay, 1963). Thus the upper limit for comfortable wind speed lies at 1 m/sec, with a speed of up to 1.16 m/sec as semi-comfortable. These evaluations are plotted in Fig. A IV.2. It is apparent from

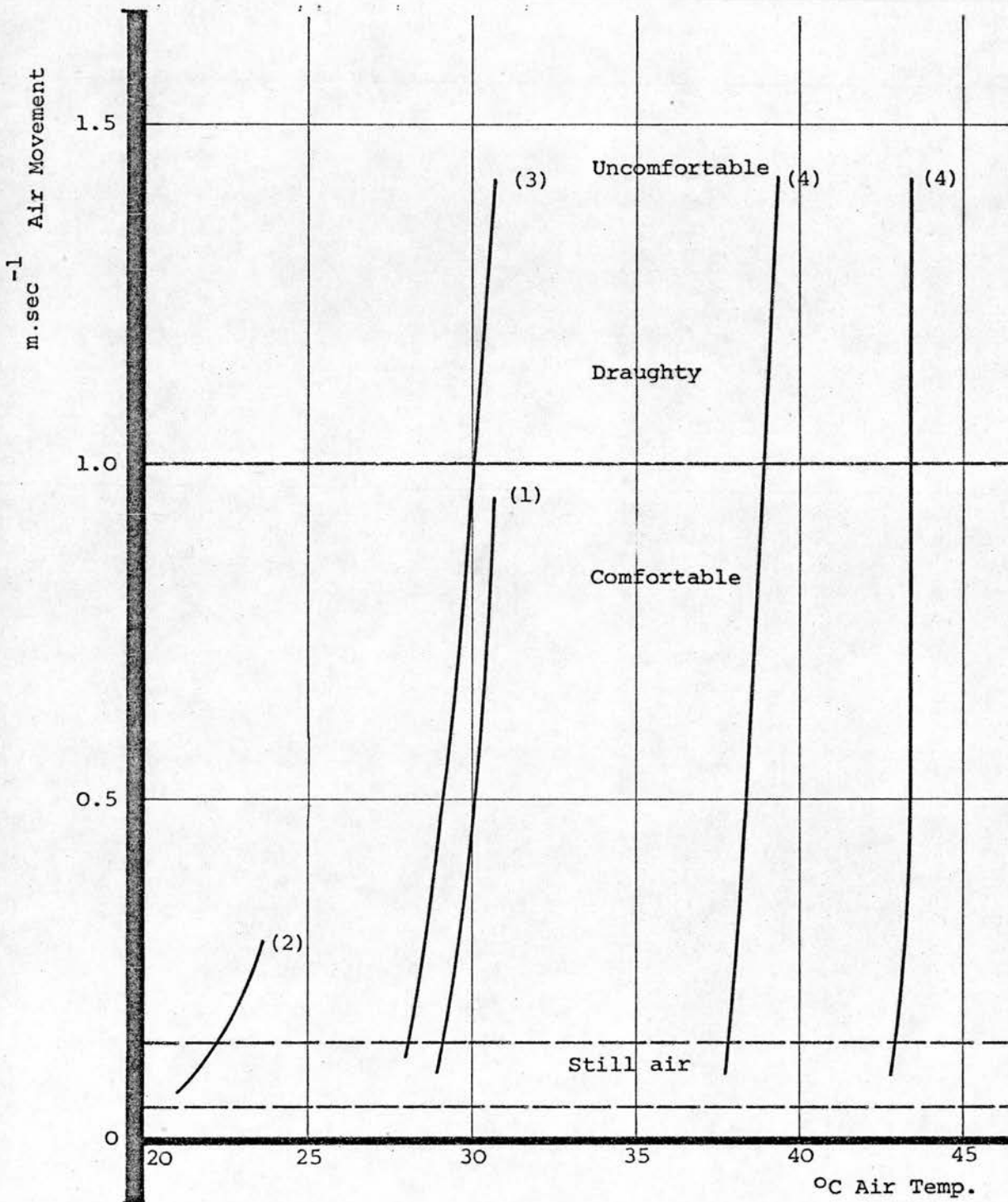


Fig.AIV.2

The cooling effect of wind at different air temps.
as evaluated by:

- (1) Richards (1959)
- (2) Investigators reported by Givoni (1969)
- (3) Olgyay (1963)
- (4) ASHRAE (1967)

the figure that the cooling effect of wind is highest at low temperatures, and the efficiency of the cooling effect is greatest at low speeds. It is also worth noticing that at 43 - 44°C air speed above 0.5 m/sec cause no rise in the cooling effect.

Conditions around 30°C are of special interest in this case since they are near the upper limit of comfortable temperatures. The cooling effect of wind at this region, as can be seen from Fig. A IV.2, is equivalent to a drop of 1°C for the first 0.38 m/sec rise in air movement. The same effect is produced by a further increase of 0.5 m/sec.

Conclusions drawn from the above discussion concerning limits of thermal comfort of man in a hot dry climate are in Chapter IV of the thesis.

APPENDIX V

The Thermal Mechanism of the Building and Its Determinants

The thermal picture of a building can be understood as the thermal exchange between the external and internal environments, governed by the thermal parameters of the building form.

A building form, from a thermal viewpoint, can be described as being constructed of opaque elements, transparent elements and openings. The thermal exchange between the external and internal environments through any of the building elements is influenced by the microclimate at the external side of the element as well as the properties of the element. These factors, and their influence on the internal thermal environment, will be discussed here in more detail for each type of building element.

1. The Thermal Exchange Through Opaque Elements

For heat to travel through an opaque element, it has to pass through two films of air, adjacent to the external and internal surfaces. It also has to cross these surfaces and the material content of the element.

1.1 The Thermal Exchange Between the External Surface and The External Environment

1.1.1 Convective

Convective heat flow is either forced by the motion of the air or caused by the temperature difference between surface and air i.e. thermal convection. The main generator of the thermal convection is the variation of the density of the air, which creates zones of varying pressures and therefore air motion. This channel of the heat exchange is, therefore, affected by the position of the surface.

When the surface is warmer than the air, its convective heat loss is maximum when it faces horizontally upwards, since low density warm air is allowed to rise and high density cold air comes in contact with the warm surface. When the surface faces downwards, the warm air stays in contact with it, not being allowed to rise, and natural convection comes to a standstill. The opposite holds true when the surface is cooler than the air, and convection becomes maximum with a downwards facing surface.

Thus, convective heating of air inside a space by its internal surfaces can most efficiently be done by its floor surface,

which might not prove to be ideal for other considerations; but when the problem is cooling the air, it is the ceiling which seems to be the most effective in this sense. Vertical surfaces can be assumed equally as effective in both cases.

The thermal resistance of the external air film is a function of its thickness, which is influenced by the velocity of the air. The thermal effect of the air film is usually described as part of the surface coefficient, which also takes into account the long wave radiative heat exchange of the surface, its emissivity, texture, position and the surface-air temperature gradient.

The importance of the wind speed in this case can be seen by comparing two values of the surface coefficient specified for American use (Van Straaten, 1967).

Wind Speed $\text{m} \cdot \text{sec}^{-1}$	Surface Coefficient $\text{W} \cdot \text{m}^{-2} \cdot ^\circ\text{C}$
3.33	22.68
6.66	34.08

The changes in the values in the table indicate a 50% rise

in the coefficient value for a 100% rise in wind speed to 6.6 m/sec.

These findings correlate with early experiments (Rowley, et al., 1930), which were carried out to find the effect of wind on the so-called surface conductance, defined as the heat flow between the surface and the surrounding air at a distance of one inch from the surface, taking into account the nature of the surface. The direction of the air motion used was parallel to the surface.

Studying the results of these experiments, one can see that for a uniform flow of heat, a drop in temperature difference from 21°C to 8°C was paralleled by a rise in air velocity of 11.1 m/sec. (Fig. A V.1). Results of the experiments of the same source show that for similar temperature conditions and an air velocity of 15.5 m/sec, the surface conductance is $58 \text{ W.m}^{-2} \text{ }^{\circ}\text{C}$ for glass, 66 for smooth plaster, 85 for concrete and 91 for brick surfaces, which proves that rough surfaces, like brick and concrete, have approximately 50% higher surface conductivities than smooth glass surfaces. The above was proved for air velocities up to 15.5 m/sec, but the results suggest similar evaluation for higher velocities.

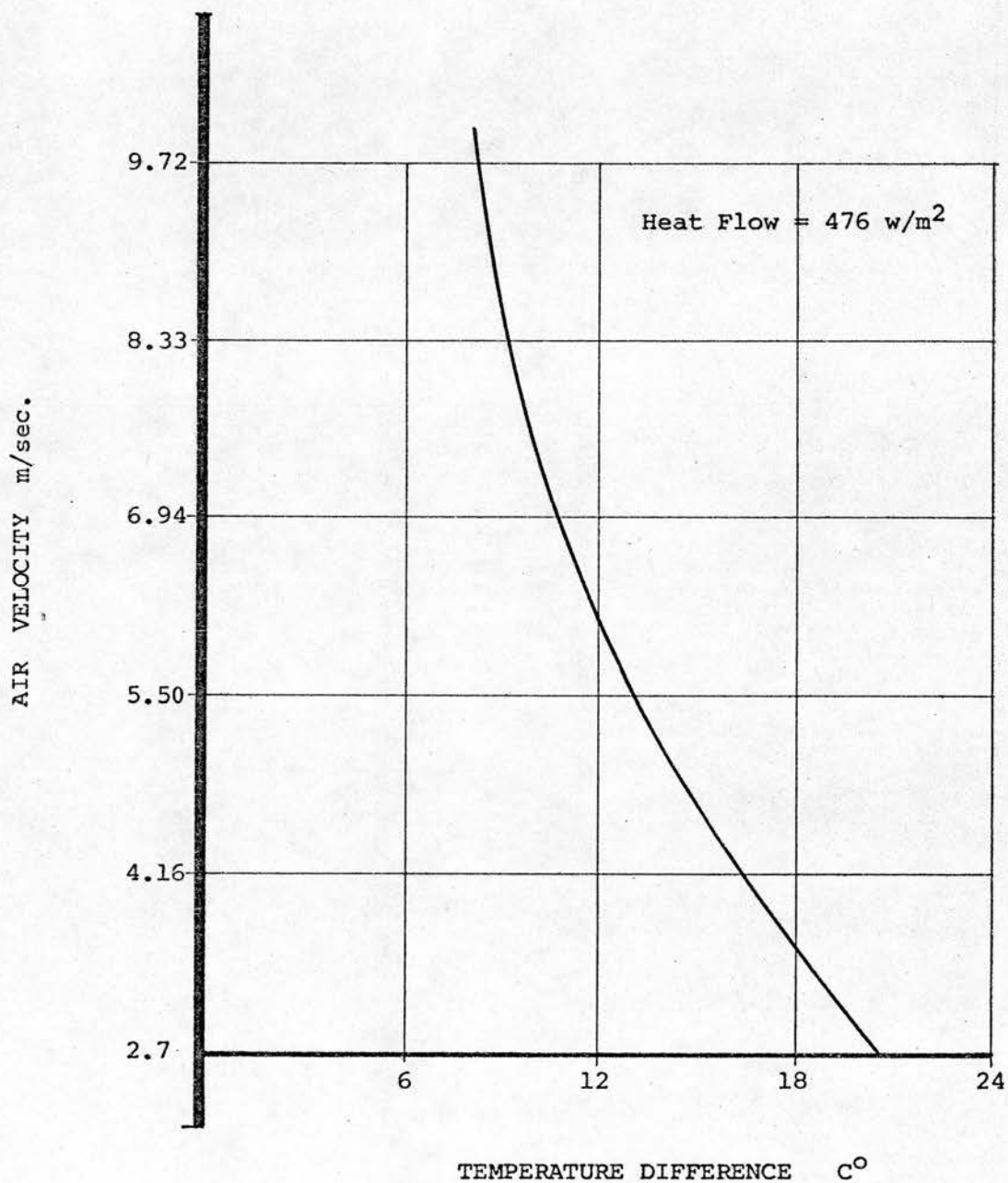


Fig. A V.1

The compensating effect of the variation in air velocity to the difference between surface and air temperature, with respect to heat exchange, taken for a smooth plaster surface.

Plotted from data given by Rowley et al. (1930)

1.1.2 Radiative

The main factors affecting radiative heat exchange at the outside surface are its reflectivity and emissivity. The first, depending on the colour and texture of the surface, decides the percentage of solar radiation absorbed. This could vary from 10-15% when surfaces are newly white-washed, to 90-95% when they are mat black. The emissivity of a building surface influences its long wave radiative heat exchange with the surrounding surfaces and the sky. It is almost equal for common building materials and independent of colour, as shown in table A V.1.

Surface	Long wave radiation Emissivity %	Solar radiation Reflectivity %
Aluminium		80-85
Asbestos (cement)	95	25-40
Asphalt pavement	95	10
Brick	90	23-40
Cement - white portland	90	60
Concrete - uncoloured	90	35
Copper and Brass		40-73
Earth		15-27
Glass	90	
Grass (Green-Dry)		5-30
Marble - white	95	55
Paint - whitewash	90	88
light colours	90	60
dark colours	90	30
black	90	15
Slate - Dark	90	10
Steel Galvanized		30-45
Tiles - red clay	90	30
black concrete	90	10
uncoloured concrete	90	35

Table A V.1

1.2 The Thermal Exchange between the External Surface and the Material Layers of the Element

The above describes the mechanism by which heat is gained at the outside surface, whether through radiation or convection. The next phase of the heat flow through the wall would be through the materials sandwiched between the outside and the inside surfaces. The fact that a wall is made of one homogeneous material or of several layers of a variety of materials, has an obvious importance in determining the nature of the heat flow. For one layer of a material, whether it forms the whole thickness of the wall or part of it, the important parameters are the thermal resistivity of the material, its thermal capacity and thickness of the layer. When several materials are put together the sequence and arrangement of the layers become of a major importance as will be described later.

The outside surface, influenced by the outside air temperature and the solar radiation incident on it, rises approaching a temperature equivalent to the air's, and as a result of the solar radiation effect it exceeds the temperature of the air, and starts having a net heat loss exchange with the immediate environment outside from one side, and the wall materials from the other. Consequently, the first layer receives heat, stores

some of it, and transfers the remainder. It is only when that particular layer's temperature is sufficiently raised, does it transfer heat to the following adjacent layer. The amount of heat stored in the layer will depend on its thermal capacity,, which is a function of the mass and specific heat of the material.

A similar procedure characterises the heat flow through the other layers and, because of the nature of the flow described above, the last heat receiving layer, i.e. the innermost, will receive the least amount of heat relative to the others, and its temperature rise will be minimum across the wall at this situation. This flow continues and heat accumulates in the wall until the outside layer reaches a balance point where heat gained from outside equals the heat lost. At this point it reaches its maximum temperature, and starts to have a net heat loss to the outside. Thus the flow of heat at this layer reverses and at some point we find a flow of heat in two opposite directions, outwards and inwards with the middle layers being of maximum temperatures across the wall.

The cooling of the layers continues until, at one stage, the temperature distribution picture across the wall is completely reversed from the daytime situation, and heat flow becomes all

in the outside direction.

From the above description of the flow it is clear that the innermost layer, and consequently the innerside surface, has the lowest maximum and highest minimum temperatures across the layers of the wall, and therefore the smallest temperature amplitude, the largest being of the outside surface. This damping effect, and the time lag between the maxima and minima of the outside and inside surfaces, are caused by the thermal capacity, resistivity and thicknesses of the materials used. In a composite wall, the arrangement and position of the different materials play an important role in deciding the character of the heat flow, since this will influence the distribution of each of the thermal resistance and capacity across the thickness of the wall.

1.2.1 The Thermal Capacity

The thermal capacity is defined as the amount of heat needed to raise the temperature of one unit volume of the material, or one unit surface area of the element, by one degree. In the first case it defines a property of the material, and its units are $\text{J/m}^3/^{\circ}\text{C}$, and in the second a property of the element, and its units are $\text{J/m}^2/^{\circ}\text{C}$.

Quantitatively, the thermal capacity of a material is given by the following relationship :

$$C = pc$$

C	thermal capacity $\text{J/m}^3/^{\circ}\text{C}$
p	density in Kg/m^3
c	specific heat $\text{J/Kg}/^{\circ}\text{C}$

of the two components, the density determines to a large extent the diversity in the thermal capacities of various building materials, since the variation of their specific heat values is a much more limited one.

As has already been described, a high thermal capacity element will produce a temperature pattern on its inside surface, such that its minimum occurs during the day, and maximum during the night. This situation raises two questions, first; how high a thermal capacity i.e. density and thickness, is needed to achieve this? and its practicability, second - how desirable is the heat dissipated through the inside surface at night? It is because of the stress caused by long wave radiative heat from the high thermal capacity walls do the people of some hot dry climates, like Baghdad, abandon their bedrooms to sleep in the open, enjoying the comfortable outside air temperature.

The Significance of the Amount of the Thermal Capacity

A small thermal capacity wall, will absorb a small amount of heat in the morning, which will elevate its temperature to a level at which it will start losing heat to the inside. Until the external conditions start to depreciate, the flow through the element is somehow similar to a steady state flow to the inside. This continues until later in the day, when external temperatures depreciate. The element in this case loses the small amount of heat it absorbed during the day, and adopts a heat flow picture similar to the daytime one, only in an opposite direction.

A too big thermal capacity wall, assuming it is newly constructed from virtually cold materials, absorbs heat at day time in an amount which would not be enough to raise its temperature to the inside air's, thus, when night comes the wall's temperature is already low and it gives only a portion of its heat away, storing the rest.

This happens through successive days and nights, and the heat accumulates until the wall reaches a stage where it has an approximately constant amount of heat stored in it permanently, and another amount being gained every day and lost every night. The surplus of thermal capacity, which caters for the constantly

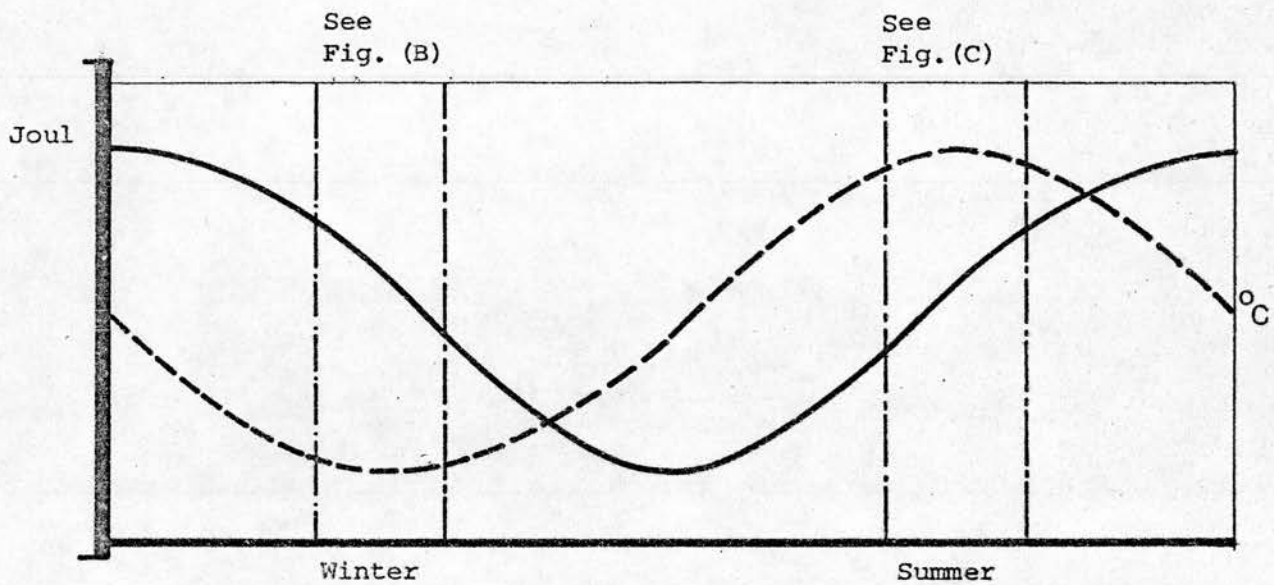


Fig. (A) Seasonal variation of air temp. and heat content of earth crust

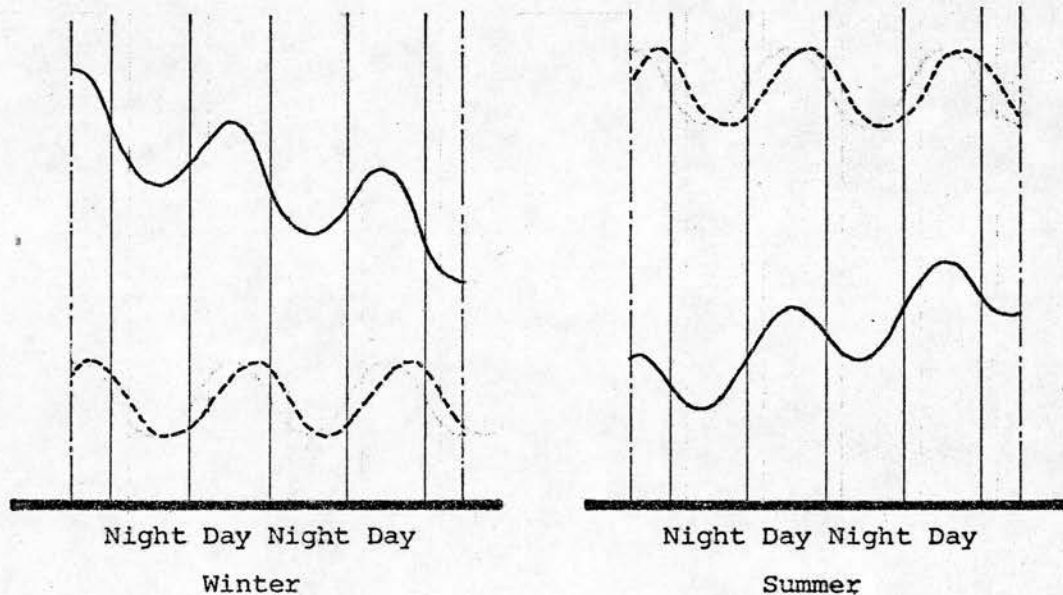


Fig. (B) Daily variation in winter

Fig. (C) Daily variation in summer

————— Daily average
 heat content
 - - - - - Daily average
 air temp.

————— Hourly heat content
 - - - - - Hourly air temp.

Fig. AV.2

The thermal logic of the subterranean house

In Fig. (C) Day heat gain, higher than night loss, cause steady seasonal elevation of heat content.

Fig. (B) Day heat gain, less than night loss, cause steady seasonal depreciation of heat content.

Fig. (A) Winter, earth releases heat to space.
 Summer, earth absorbs heat from space.

stored heat, is in this sense a waste and causes stress on summer nights by keeping the element temperature higher than the space's. The optimum thermal capacity here would be that which does not store this surplus, but is high enough not to make the inside surface temperature approach the inside space temperature, i.e. cooler during the day.

The case of the very high thermal capacity can rarely be useful, and that is when it is high enough to delay the accumulation of heat for a complete season, e.g. accumulating heat during the summer by absorbing it at daytime and losing a smaller amount at night, until winter comes where the reverse happens, and a slow cooling of the mass occurs by giving heat, maximum at night time when most needed and less during the day. This situation can only be achieved through using a fantastic mass like the Earth, in which the troglodytes of Matamata in Tunis, and the Chinese of Honan have dug their homes.

In building practice, the thermal capacity of an element is represented by a heavy material like brick or concrete, which at the same time provide a considerable amount of thermal resistance. Table A V.2 lists values of the thermal properties of elements of various common building materials, and a range of thicknesses.

1.2.2 The Thermal Resistance

The thermal resistance of an element is the reciprocal of its thermal conductance (K).

Table A V.2

THERMAL PROPERTIES OF SOME COMMON BUILDING MATERIALS

Thickness m	Material	Density kg.m^{-3}	Specific Heat $\text{J.kg}^{-1}.\text{°C}^{-1}$	Thermal Capacity $\text{kJ.m}^{-2}.\text{°C}^{-1}$	Thermal Resistance $\text{m}^2.\text{°C.w}^{-1}$
0.12	Brick-clay	1800	754	163	0.146
0.25				339	0.301
0.36				488	0.438
0.50				678	0.608
0.10	Concrete - Dense	2300	879	202	0.069
0.20				404	0.146
0.30				607	0.215
0.40				809	0.284
0.50				1011	0.361
0.10	Concrete - Lightweight	600	879	53	0.344
0.20				106	0.688
0.30				158	1.032
0.40				211	1.376
0.50				264	1.720
0.015	Plaster - cement	1762	921	24	0.022
0.045				73	0.067
0.015		1282	1089	21	0.032
0.045				63	0.095

(K) is the amount of heat transfer across the element per unit temperature difference per unit time. The units of thermal resistance are therefore $\text{m}^2 \cdot ^\circ\text{C}/\text{W}$. For a homogeneous element it is given by the following equation :

$$R = \frac{l}{k} \quad \text{where} \quad K = \frac{k}{d}$$

R	Thermal resistance of the element
K	thermal conductivity of the material
k	thermal conductance of the element
d	thickness of the element

The thermal resistance of a multi-layer element is given by the following equation :

$$R = R_o + R_1 + R_2 + R_i$$

where

R	thermal resistance of the element
R_o	thermal resistance of the outside layer
R_1, R_2	thermal resistances of the middle layers
R_i	thermal resistance of the inside layer

Determinants of the Material's Thermal Resistivity

The factors determining the resistivity of a material have been specified by Close (1966) as being :

A. Substance: Materials are generally categorized into two types, good conductors like metals and brick; and poor conductors like insulating materials.

B. Subdivision or Density: For a particular material the conductivity depends on its conditions of subdivision.

For most insulating materials, their conductivity increases with their density. This factor, however, may not have as great an influence on the conductivity of the material, as would factors like moisture, arrangement, and character of the fibres in a fibrous material. Laminating and arranging the fibres of a structural insulating board so that their direction is generally perpendicular to the heat flow improves their conductivity.

The density - conductivity relationship, in some materials, has a critical point which yields a minimum heat flow. Close (1966) describes that the decrease in density of certain materials beyond a particular point is likely to promote flow of heat by convection, which outweighs the added resistivity.

C. Moisture: The water which fills the voids has a greater

Table A V.3

THE THERMAL RESISTANCE VALUES (R VALUES) OF SOME INSULATING MATERIALS

Thickness m	Material	Density kg. m ⁻³	Thermal Resistance m ² °C.W ⁻¹
0.005 0.01 0.05	Balsa Wood	40	0.1254 0.2508 1.2539
0.005 0.01 0.05	Blanket - -wool, closely woven	65	0.1168 0.2336 1.1679
0.005 0.01 0.05	Felt - -wool	150	0.1282 0.2565 1.2825
0.005 0.01 0.05	Corkboard	130	0.1254 0.2508 1.2539
0.005 0.01 0.05	Polystyrene -expanded board	25	0.1354 0.2708 1.3542
0.005 0.01 0.05	Polyurethane -gas filled rigid board	30	0.2508 0.5015 2.5077
0.005 0.01 0.05	Polyurethane -aged	30	0.1927 0.3862 1.9274
0.02-0.1	Air space -vertical -horizontal (heat flow upwards) -horizontal (heat flow downwards)		0.1634 0.1505 0.1892

conductivity than the air it replaces, and thus it increases the rate of heat flow through the material.

- D. Mean Temperature: Most homogeneous insulating materials experience a small increase in their conductivity with the mean temperature of their two surfaces, even for the same temperature difference. This effect can be considered as of little significance for building practice.

Table A V.3 lists values of the thermal resistances of a variety of insulating materials with a range of thicknesses.

1.2.3 The R-C Compositional Relationship

For the composition of an insulated heavy wall, time factor has to be taken into consideration. The temperature of the inside surface of a high thermal capacity material, having a considerable time lag from that of the outside surface and air, reaches its minimum value during the overheated hours of the summer day and, if exposed to the inside space i.e. no internal insulation, will help moderate day thermal conditions. The case for external insulation has been put forward by Van Straaten (1967) and Givoni (1969) in discussing

the mechanism of the heat flow to the inside, and also in considering the insulation as a protection for the structure from the intense heat, thus reducing its thermal movement.

A study of the characteristics of the hot dry climate, and a consideration of the thermal properties of building materials, have led several researchers to specify heavy construction for day time use spaces, and light construction for night time use ones (Atkinson, 1950 and Muncey, 1961). This conclusion is built on the understanding that a heavy structure, storing heat supplied from outside during the day, will only elevate internal thermal conditions at night, which are otherwise near comfort, to an uncomfortable level. This kind of specification of spaces according to use time, forces the uneasy limitation on the versatility of the space and the efficiency of its use.

Calculations by Dreyfus (Givoni, 1969), allow a comparison between two 10 cm concrete roofs with identical insulating materials applied externally to one and internally to the other, table A V.4.

Exterior to Interior Composition	cm Thickness	Decrement Factor	Time Lag
Rockwool	4	0.046	11h 50min
Concrete	10		
Concrete	10	0.45	3h
Rockwool	4		

Table A V.4

Calculations of decrement factor and time lag of
two roofs by Dreyfus.

From the above table it is clear that the advantage of a large time lag, gained by using external insulation, is paralleled by a depreciation in the decrement factor. This provides a strong case for exposing the mass of the element to the outside during the night to lose its heat and sheltering it during the day.

Adaptable Insulation

At this point one can suggest the use of a movable insulating screen, e.g. wool felt, to a heavy structure being applied

internally at night, thus letting it cool by losing heat to the outside, and externally during the day, giving the composition the double advantage of being protected from excessive external heat gain and moderating the internal thermal conditions, which are likely to be at a higher level than the pre-cooled high capacity material.

Reversing the process during the winter season can utilise the heat received by the outside surface during the day through the still considerable amount of solar radiation (see Appendix VIII) in helping to elevate internal night time thermal conditions, and at the same time preserving the day-time internal heat from being absorbed into the high thermal capacity structure. (Fig. A V.3).

Experiments on movable insulation over roof ponds were carried out by Hay (1971). The construction consisted of a water pond with a black liner in its bottom and slabs of insulation which can slide providing a cover to the pond. The principal behind the experiment was to expose the pond to day radiation in winter time. The black liner absorbs the solar heat and transfers it to the ceiling, and therefore the inside space, or to the water to be stored. At night time, the movable insulation was applied to protect the stored heat from being

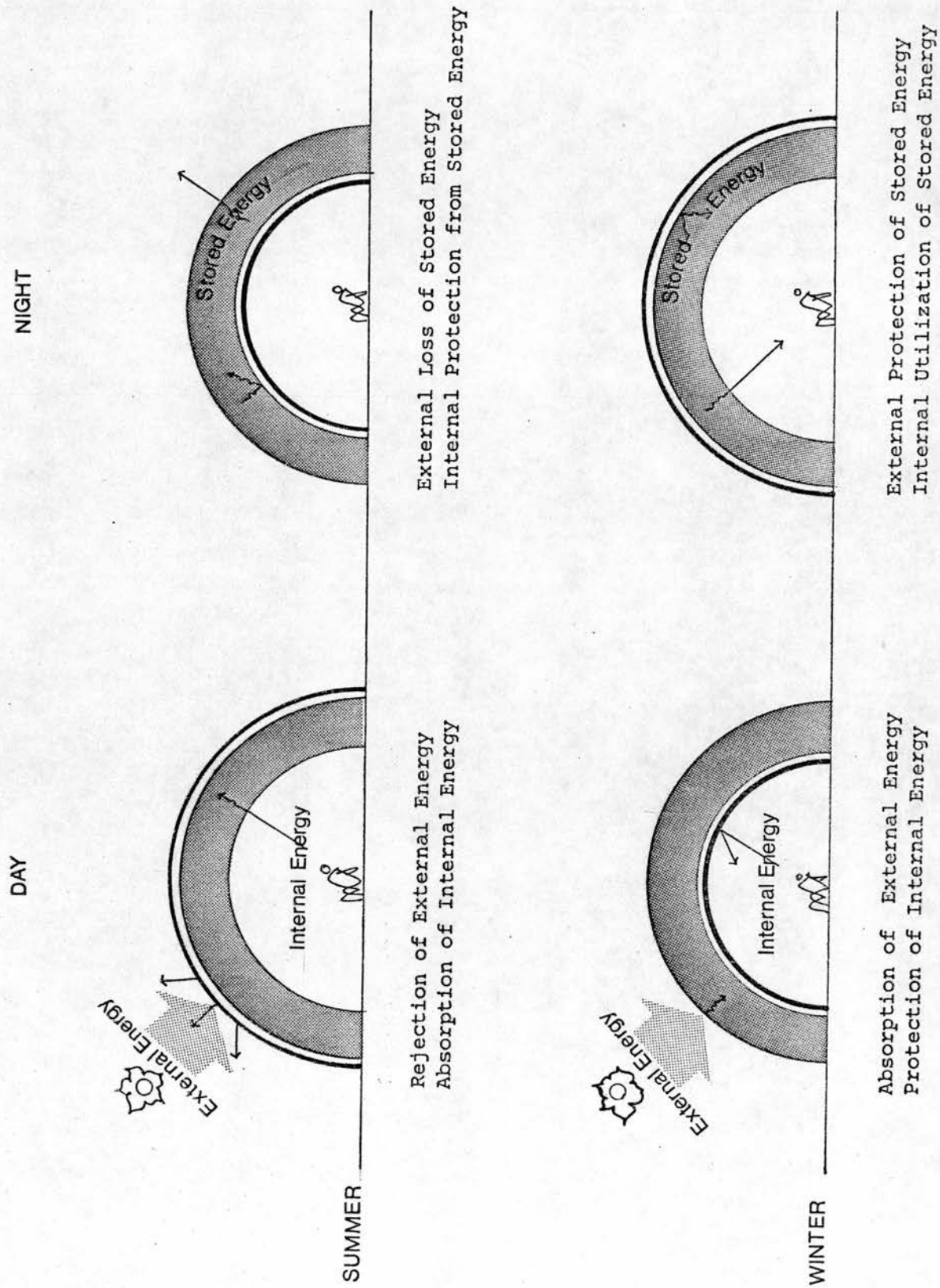


Fig. A V.3 The Use of Adaptable Insulation to Better Thermal Design

lost to the sky. In summer time the operation was reversed by using the evaporative, radiative and convective night cooling of the water, and protecting it from the sun during the day. Hay reports a considerable success in maintaining comfortable inside temperature in the hot arid summers of Phoenix, Arizona.

Movable thermal insulation and the use of heavy constructional materials as heat storers is a field for further research which can contribute to better thermal design in the hot dry regions.

2. The Thermal Exchange Through Transparent Elements

The role of glazed elements in the heat exchange between the external and internal environments is of major importance owing to the thermal properties of glass. It is possible to treat this problem as of two components, the radiative heat transmission and exchange, and the conductive heat exchange.

2.1 The Radiative Transmission and Exchange

To explain the radiative heat exchange through glass, which

special properties in this sense make it unique compared to other building materials, we consider the radiation incident on it.

A glazed element receives solar radiation in a reflected, diffused, or direct form. The first two types are received through the sky and neighbouring reflecting surfaces, like buildings and topography. Their intensity depends on the clarity of the atmosphere and the reflectivity of these surfaces. The intensity of their incidence is a factor of the exposure of the element to these diffusers and reflectors.

The solar radiation arriving at the surface of the earth is in a wavelength band approximately between 0.3 micron and 3 micron. This range is divided into three regions, ultra violet between 0.3 and 0.38 micron, visible radiation between 0.38 and 0.76 micron, and infra-red beyond 0.76 micron. As can be seen in Fig. A V.4, although the maximum intensity of solar radiation occurs in the visible range, over 50% of the emitted energy is of the infra-red radiation.

Glass divides the incident solar radiation into three parts, reflected, absorbed and transmitted. The ratio of each to the total is dependent on the angle of incidence and the

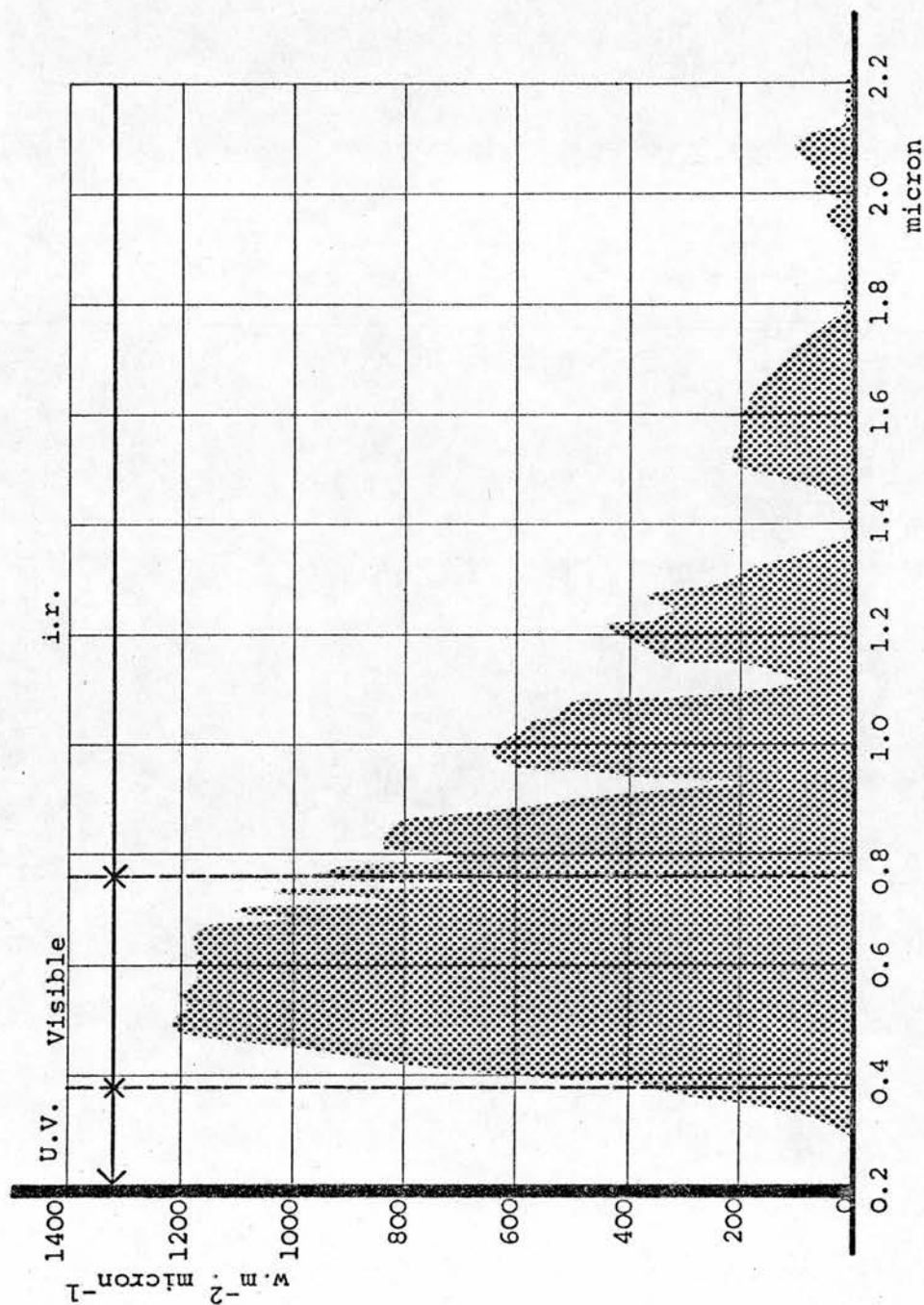


Fig.AV.4
Solar Energy - The Spectral distribution at an altitude of
30° as presented by Turner (1969)

spectral properties of the glass. While transmitting nearly 80% of the normally incident radiation of a wavelength between 0.3 and 2.7 micron, float glass has an approximate transparency of 10% for 2.8 - 4.0 micron wavelength, and is completely opaque for the long-wave radiation of 10.0 micron. (Fig. A V.5) The fact that glass is highly transparent to the most intense part of the solar spectrum, and opaque to the longwave thermal radiation, make it a building element of high criticality to the internal thermal environment, especially in a hot climate.

The percentage of reflected radiation is a function of the angle of incidence. It is less than 0.1% when the angle is between 0° - 50° . Beyond this range the reflectivity takes a fast progressive rise approaching complete reflectivity with an angle of 90° . Depending on the kind of glass, a portion of the radiant energy is absorbed by it, and then released to both sides of the panel by longwave radiation and convection. The heat contribution to the inside by this channel is of little relative value in the case of ordinary glass, and it generally constitutes 5% of the total incident solar radiation normal on glass (Givoni 1969).

Working towards a glass with improved radiative transmission qualities, many types of glass have been industrially developed.

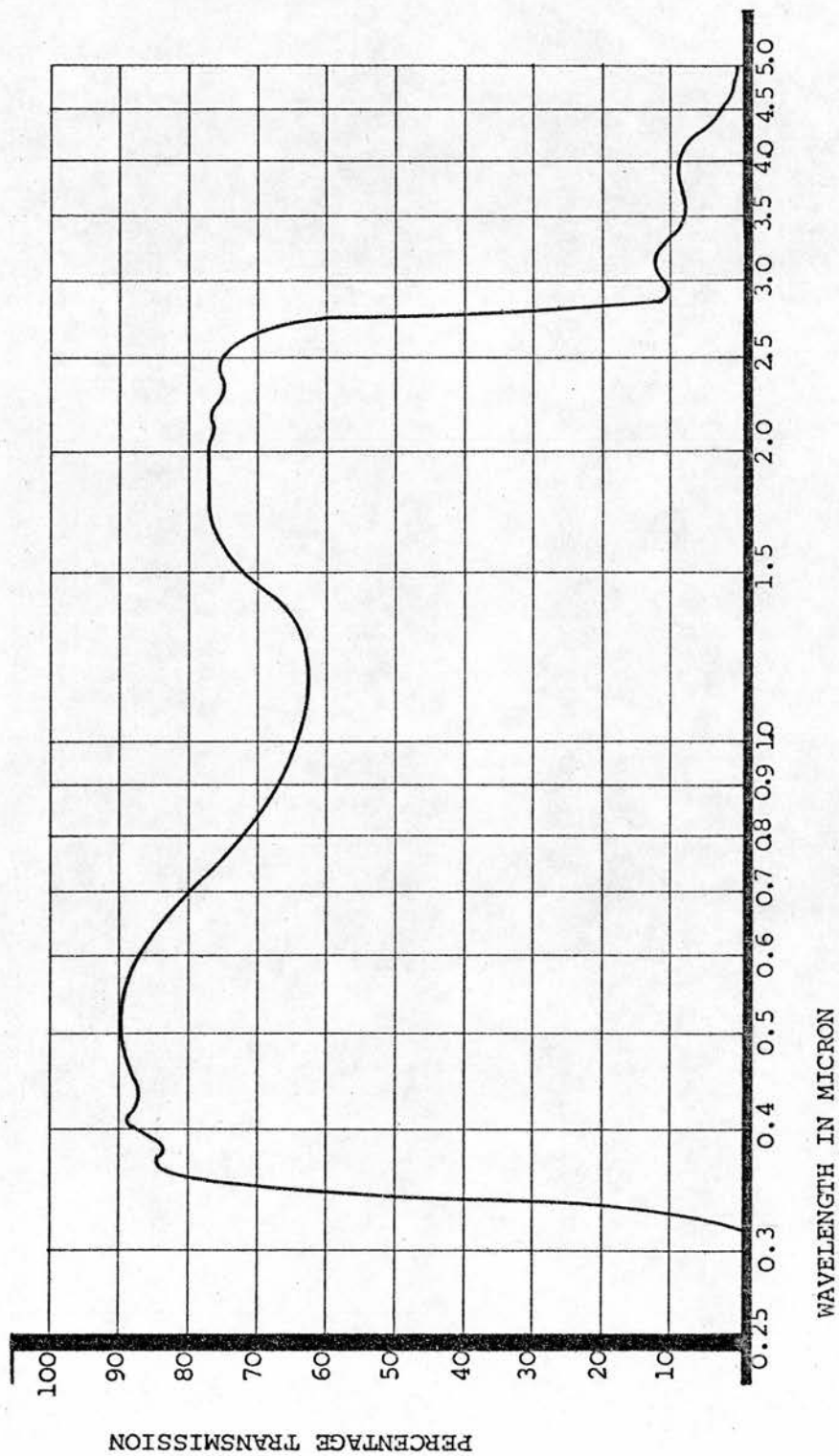


Fig. A VI.5
The spectral transmission characteristics of 6 mm float glass
After Turner (1969)

They can be categorized into radiative heat absorbers and radiative heat reflectors.

Heat absorbing glass, owing to its high content of iron oxide, has a particularly high absorptivity to infra-red radiation, but transmits most of the visible, shorter wave radiation. The deposition of fine metallic coatings on the surface of clear glass makes it approximately equally reflective to all wave lengths of the radiation. But this "heat reflecting glass" needs to be double glazed or laminated in order to protect the reflective coat from mechanical damage. The content of thermally sensitive or photosensitive materials by glass causes an increase to its reflectivity when exposed to a high intensity of solar radiation. The use of this kind of glazing has been very limited due to technical and economical reasons.

From the above study, one can see that a proper evaluation of the performance of glass, in the radiative heat exchange between the external and internal environments, can only be made by an appreciation of the proportion of incident radiation that is directly transmitted, and the fraction which is absorbed and released inwards. By computing the percentages of the incident solar radiation that are reflected, absorbed,

or transmitted; and the proportions of externally and internally released parts of the absorbed energy, Turner (1971) set curves showing a comprehensive evaluation of the transfer of incident solar radiative heat of a variety of glazing types plotted as a function of the angle of incidence.

(Fig. A V.6)

2.2 The Conductive Exchange

The value of this channel in the heat exchange process through the glass element is dependent on the external-internal temperature gradient, and the speed of air on either surfaces. These two parameters affect the heat flow through glass like an opaque element, which has previously been discussed in this appendix.

The non-climatic parameters affecting this conductive exchange are the thermal resistance and capacity, with the latter being of negligible value. The thermal resistance of glazing is a function of its construction, e.g. single or double glazing. IHVE (1970) calculated the thermal resistance of single glazing by adding the external and internal surface resistances. In the case of double and triple glazing, the resistances of the

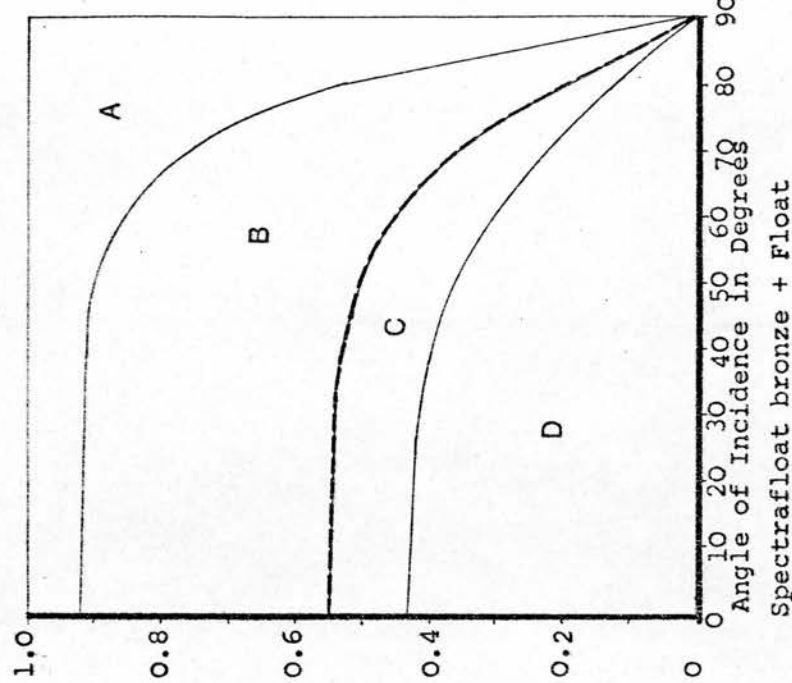
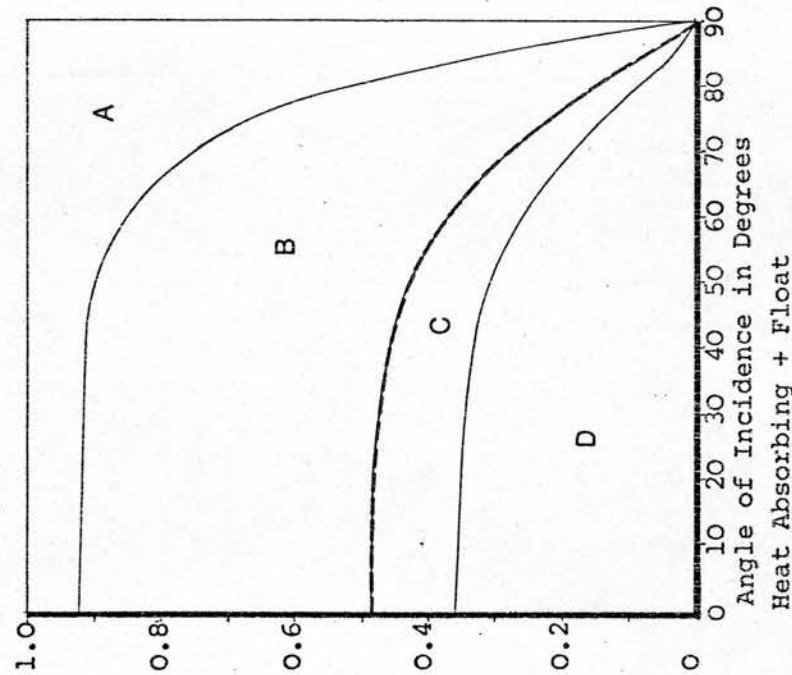
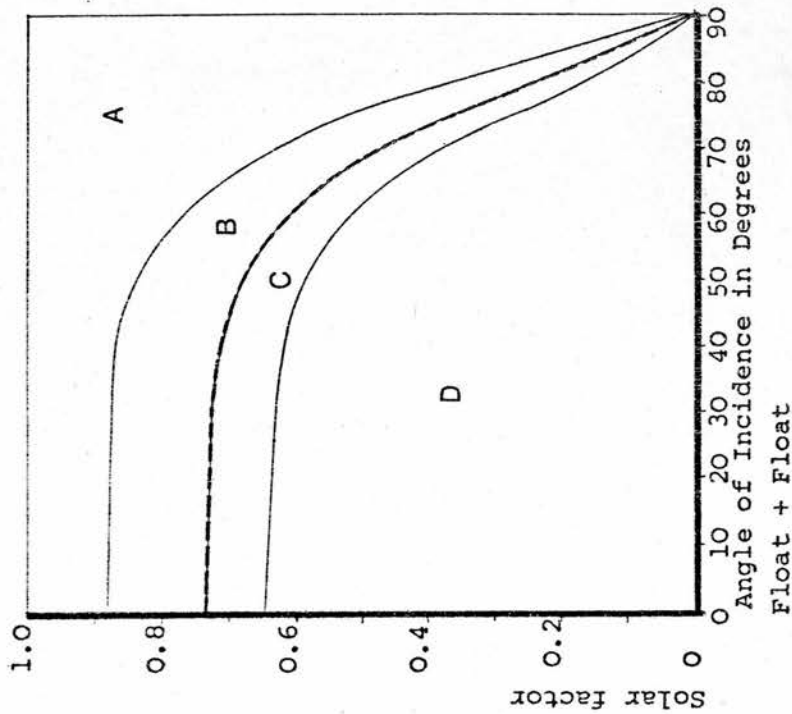


Fig. A V.6.1 (Turner, 1971, pages 324-326)

The solar factor for a variety of glazing as a function of the angle of incidence of solar radiation

- | | | |
|-------|---|--|
| ----- | A | Reflected radiation |
| | B | Absorbed radiation - released outwards |
| | C | Absorbed radiation - released inwards |
| | D | Transmitted radiation |

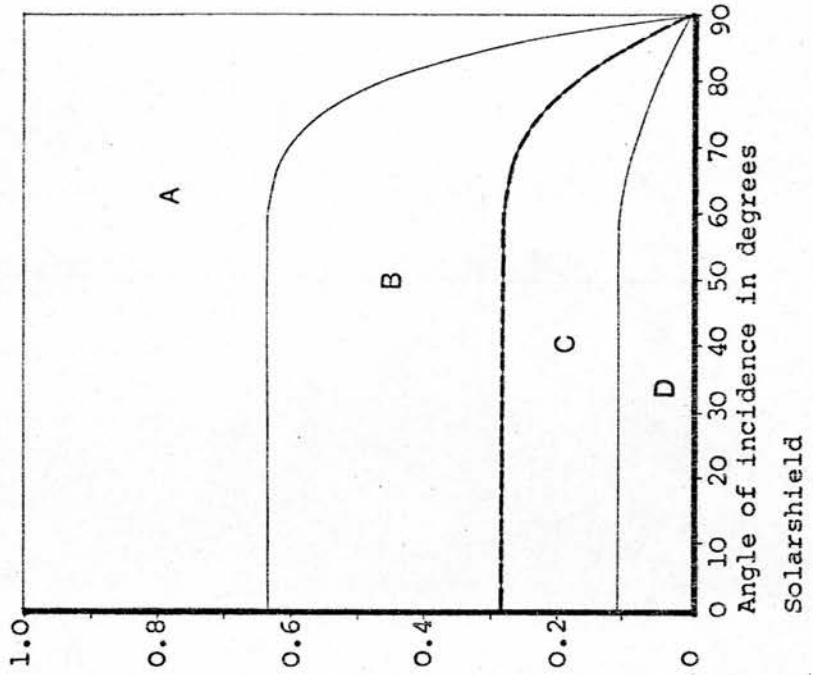
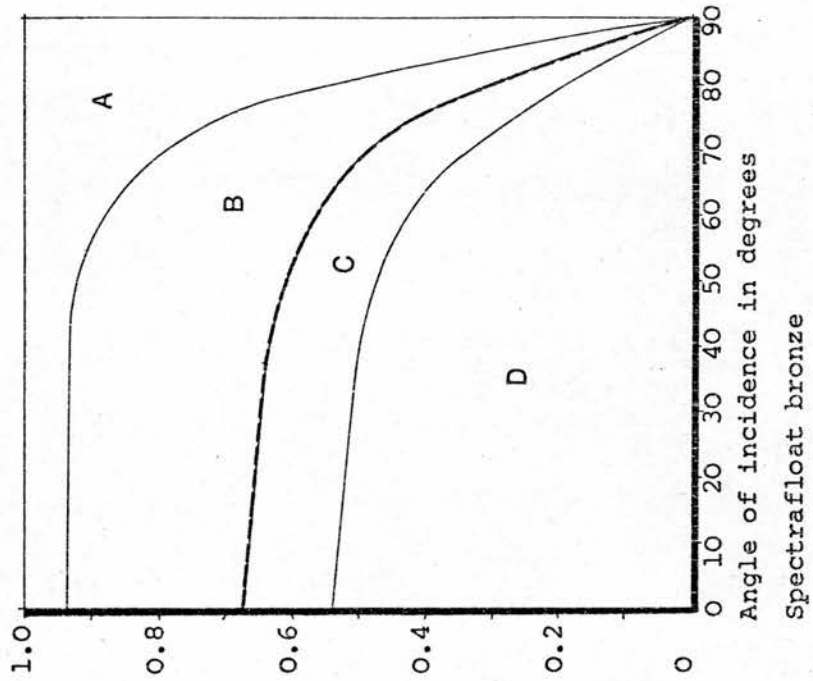
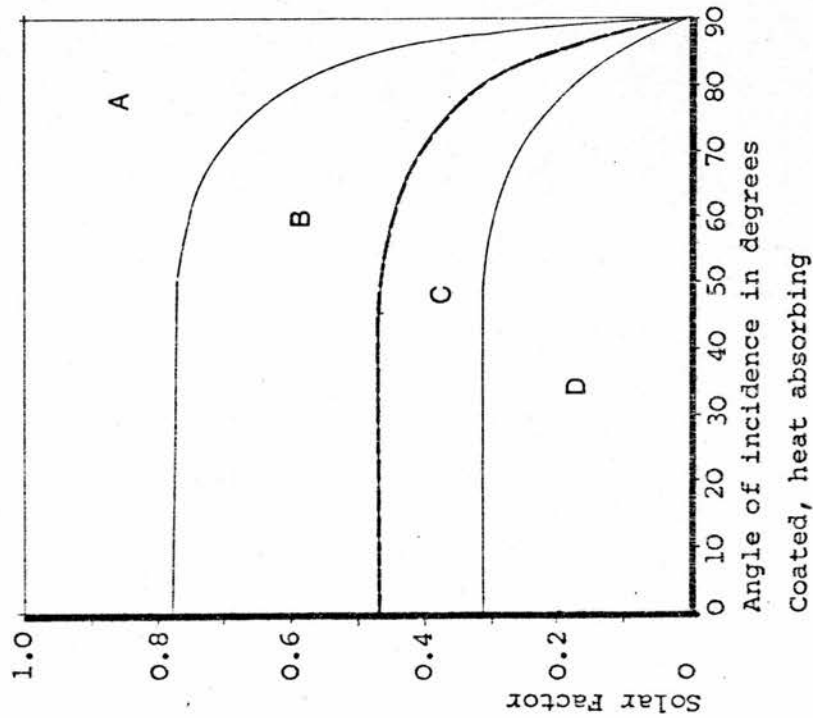


Fig. A V.6.2 (Turner, 1971, pages 324-326)

----- The solar factor for a variety of glazing as a function of the angle of incidence of solar radiation

- A Reflected radiation
- B Absorbed radiation - released outwards
- C Absorbed radiation - released inwards
- D Transmitted radiation

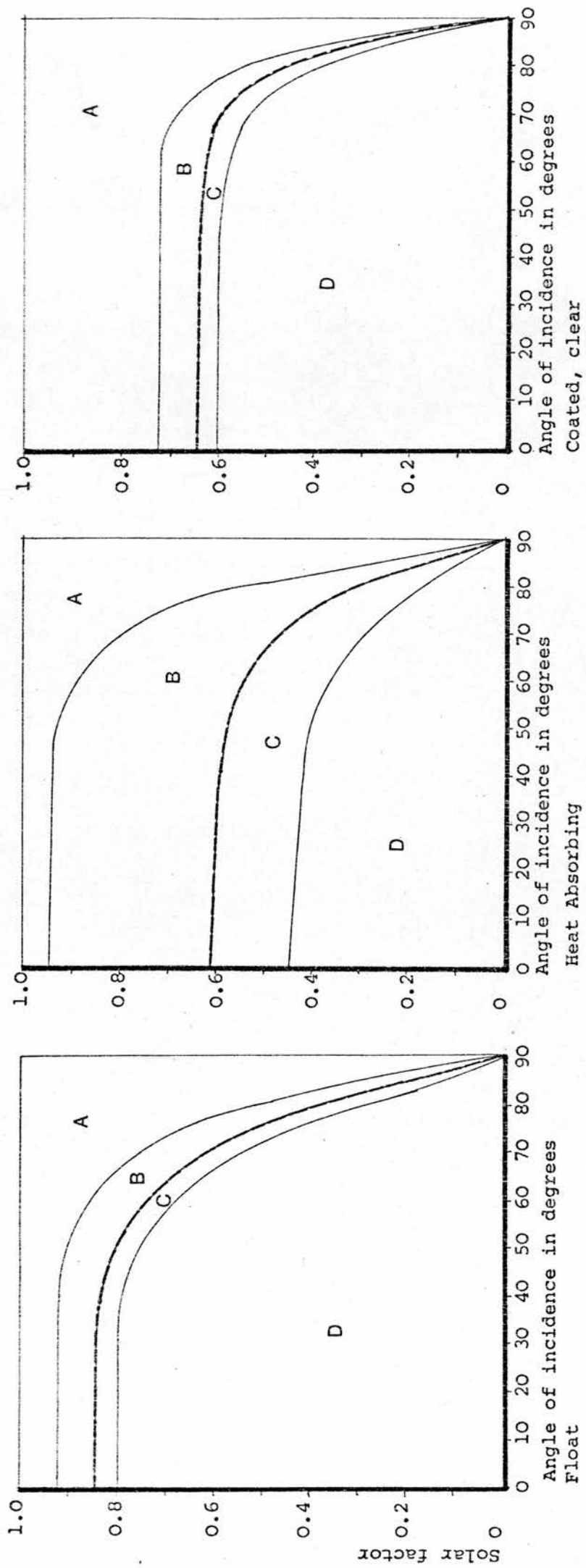


Fig. A V.6.3 (Turner, 1971, pages 324-326)

----- The solar factor for a variety of glazing as a function of the angle of incidence of solar radiation

- A Reflected radiation
- B Absorbed radiation - released outwards
- C Absorbed radiation - released inwards
- D Transmitted radiation

air spaces were also added. These values are given in the following table :

Glazing Type	Thermal Resistance
	$\text{m}^2 \cdot ^\circ\text{C}/\text{W}$
Single	0.18
Double	
Air Space (mm):	
20	0.345
12	0.33
6	0.29
3	0.25
Triple	
Air Space (mm):	
20	0.5
12	0.48
6	0.4
3	0.33

Table A V.5

The Thermal Resistances of Various Types of Glazing. IHVE (1970)

3. Natural Ventilation

So far the discussion has been concerned with the modifications of the elements of the external thermal environment as they filter through the building elements. The introduction of natural ventilation to a building space can be described as the entrance of the external air temperature to it, without modification. In regions of hot dry climates, this would prove to be a major disadvantage at a great majority of the year, since air temperatures experience considerable annual and daily fluctuations, as can be seen for Baghdad in Appendix VIII.

3.1 The Mechanism of Natural Ventilation

3.1.1 Thermally Induced Ventilation

The above mentioned properties of glass have a great effect in raising the inside air temperature and thus stimulating the so-called stack effect in the building, i.e. thermally forced ventilation. The natural flow of air in and out of a building is generally generated by two factors, thermal forces and wind pressure. Changes in the temperature of the air cause variations in its density and thus create pressure differences causing the flow of air. When a window is open at any point in

the wall, a balance is created at both sides of the aperture and air pressure equalises, thus air flow through the window comes to a standstill, but air pressure at other heights from the aperture varies owing to the variation in density.

Considering the air indoors as being hotter than outdoors, and subsequently less dense, the pressure outside at a certain level above the aperture will be less than the pressure at the same level inside. The difference increases with the elevation above the aperture. This pressure gradient is reversed at levels below the aperture, and a negative of the whole picture is true when inside air temperature is lower than that of the outside.

It is only when another opening is made at a point with a pressure difference i.e. different level from first opening, does the air start to flow. At the higher opening, the pressure inside is in excess of the pressure outside and thus air starts to flow out; at the same time a pressure gradient in the opposite direction is formed at the lower aperture, and air starts to flow to the inside. The opposite to this procedure will hold true when outside air has the higher temperature.

Magnitude of the thermally induced air flow is determined by

the difference in height between the two apertures, the difference in their air temperatures and their areas. The relationship is explained by the following equation :

$$F = KA \sqrt{H \Delta T}$$

where

F	air flow $\text{m}^3 / \text{min} \cdot \text{m}^2$
K	constant depending on type of openings
H	vertical distance between the two openings (m)
ΔT	outside-inside air temperature gradient ($^{\circ}\text{C}$)
A	the area of the smaller opening

Since this flow of air or stack effect is a function of the height it increases with the height of the building, multi-storey buildings can have an appreciable amount of flow, with the vertical links like the lift shafts and stairwells acting as air passages. Single or two storey houses cannot have an effective, thermally induced flow unless there is a big inside-outside air temperature difference, which can only be obtained in the winter of cold regions (Van Straaten, 1967), or by the use of ventilation shafts to increase the inlet-outlet difference in height. A similar concept to the breeze catchers, designed for this purpose might prove to be an effective means

provided that the designer is aware of the wind behaviour.

3.1.2 Wind Induced Ventilation

The wind is the other generative force of natural ventilation. When it is obstructed by the building, zones of positive and negative pressures are formed, i.e. high and low pressures. The speed of the wind at high pressure zones is usually low, but when two openings are provided at the two different zones air starts to flow inside the space, with the opening at the higher pressure acting as an inlet and the other as an outlet. What decides the amount of flow between the two is the pressure difference and the inlet-outlet area ratio. The pressure magnitudes at the inlet and outlet points are decided by the speed of the wind, the orientations of the openings in relation to its direction and the design of the apertures.

This method of inducing air flow in a building is a much more effective one than that of the thermal forces, because it directs the air flow inside the space owing to the velocity the air originally has when entering through the inlet. It has been found (Givoni, 1969), that when two openings are provided in the same wall at different heights, with the air being still, the flow of air follows the shortest path along the wall between the openings and air motion in the room is least affected. Thus, it can be said that wind induced ventilation is more effective

than the thermally induced.

The idea underlying the above discussion of the thermal mechanism of the building has been the separation of the three channels of the heat exchange between the external and internal environments. These channels are the opaque elements, the transparent elements and natural ventilation openings. In the built environment, however, these effects are coincidental. Their interactions, if viewed simultaneously, would produce a picture that is complex, confusing and difficult to describe.

TRADITIONAL ARCHITECTURE OF BAGHDAD

Unless otherwise stated, photographs and measured drawings were prepared by the author.

1. The Vernacular House in the Regional Context

The climate of Iraq varies considerably between its geographical extremities. It is cold to temperate in the north mountainous areas, hot dry in the central parts and hot humid in the south. The diversity in the climate is reflected in the architectural expressions of the various parts of the country. This can clearly be seen in vernacular houses of each region.

A village house in the northern mountains is usually a small rectangular unit made of brick and stone for the walls and dried tree branches topped with earth for the roof. In general, the characteristics of the house and the form of the village reflect the cultural background of their inhabitants, the Kurds, and the physical nature of the area. Climatically the houses depend on having elements of heavy materials and a limited number of small area windows. The overall concept seems to express the undesirability of the instantaneous effect of the penetration of solar

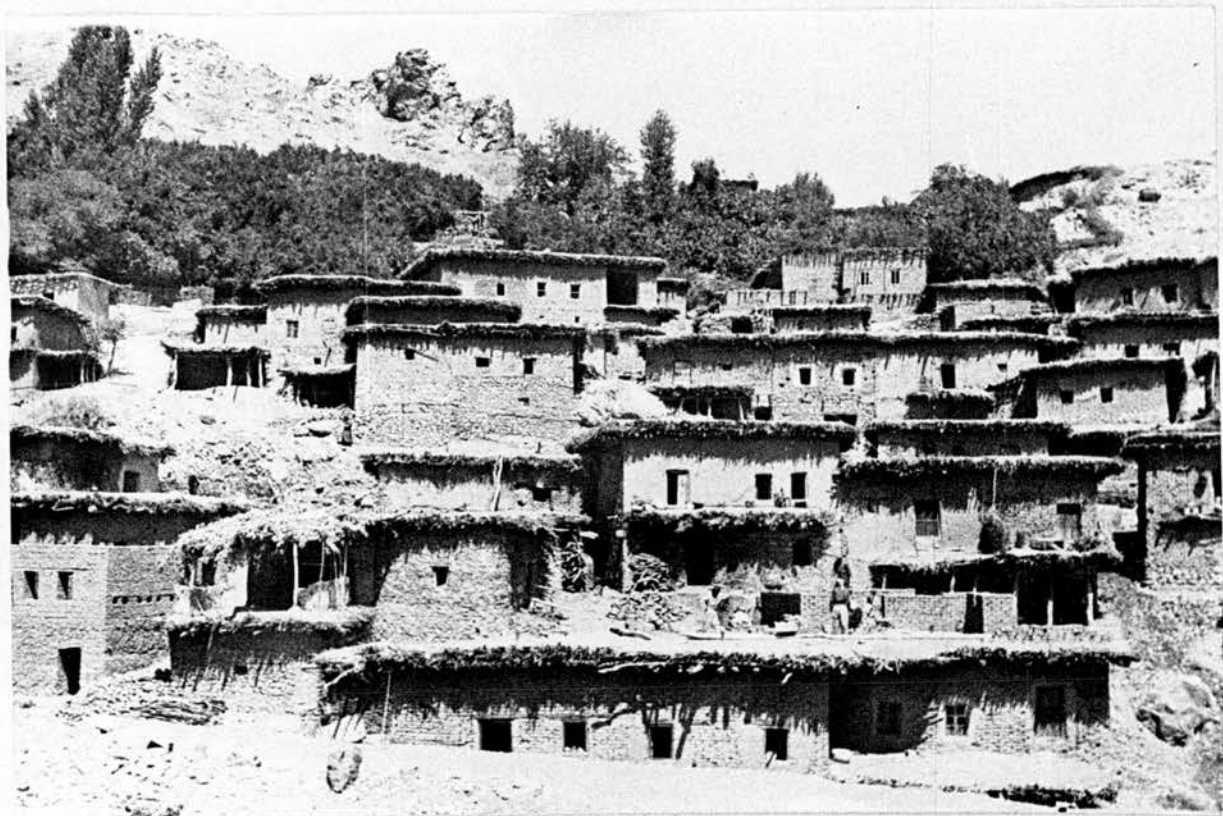


Fig. (AVI.1)

A village in the mountainous north of Iraq.

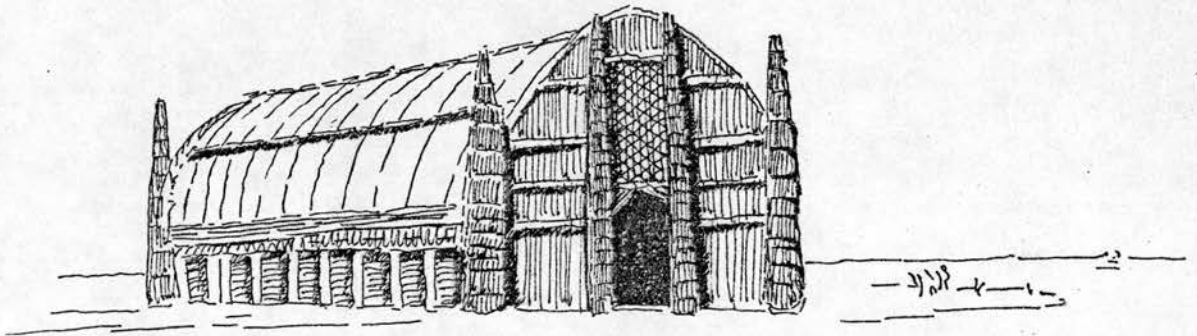
radiation through windows compared with the regulated effect of its incidence on the high thermal capacity walls (Fig. A VI.1).

In sharp contrast to the vernacular of the north is that of the marsh areas of the south, where the air temperature is high and the humidity is considerable. The dwellings in this case are made solely of reed, which grows in abundance in the area, and built on scattered small islands, thus encouraging air movement. This is carried further to the inside through the reed mesh which forms the two end walls. The reed seems to provide the ideal light material with a fair amount of thermal resistance (Fig. A VI.2). Externally the palm tree is a very strong element in the setting. It provides good shelter from the sun and avoids obstructing air movement near the ground.

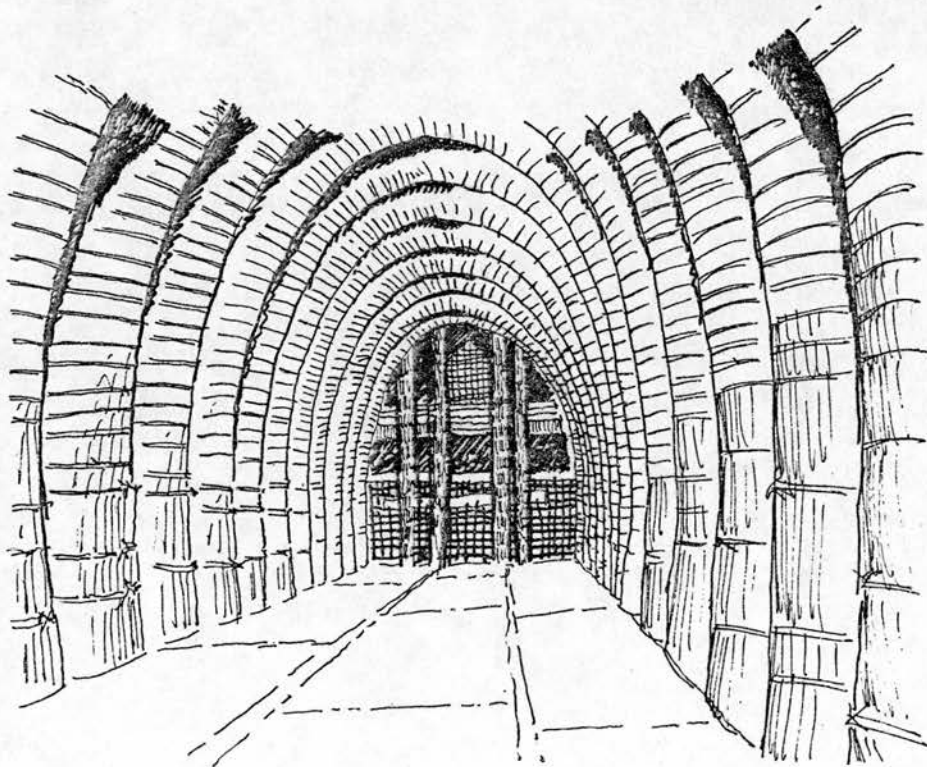
This house and that of the northern mountains are two examples of village architecture of the north and south of Iraq. As of the central areas the courtyard house of the old Baghdad stands as a case of special interest to this study.

2. The Courtyard House of Baghdad

Variable versions of the courtyard house principle can be found in the regions south and east of the Mediterranean. These regions



Exterior



Interior

Fig. A VI.2 The Reed Dwelling

cover North Africa starting at the Atlantic across to the Near East and through to India (Dunham, 1960). Thus the CY house seems to exist in areas of differing cultures and similar climates, arid or semi-arid, which supports the view that this form of house is more specific to the climate than it is to the culture in which it exists. To present a more complete picture the CY house should be discussed within the context of the urban pattern of the old city.

The form of the residential part of old Baghdad is one of a uniform, continuous layer of two storey CY houses of rectangular and rhomboidal shapes, fed by a pattern of branching streets and alleys varying in width. The CY house is basically two floors of rooms surrounding one central space open to the sky. It is usually attached to neighbouring CY houses from three sides and has one external facade to a narrow street. The rooms of the house are provided with natural light through windows in the CY facades. At ground level the CY serves as a major circulation space connecting the various rooms. This function is provided for at first floor level by a peripheral balcony. Two other spaces are often included, the basement (or serdab) and the kebishkan which is an intermediate storey in the first floor.

The constructional concept of the house is especially interesting. It seems to depend on a contrast of two kinds of masses which stems from the use of two materials of widely varying characters in a

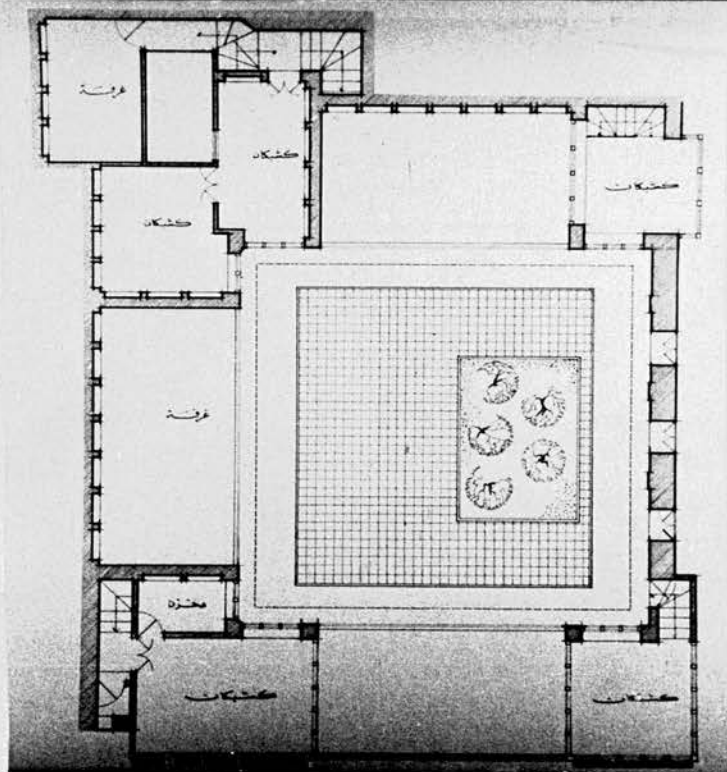
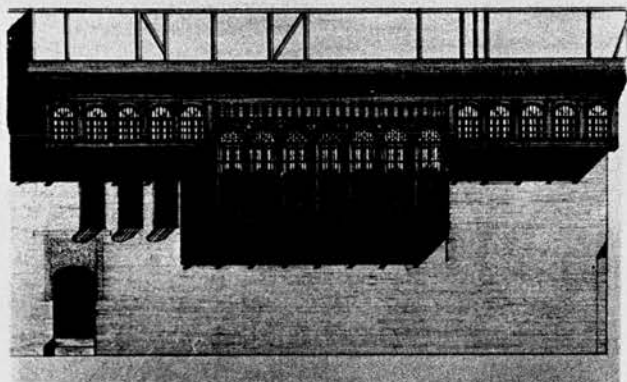
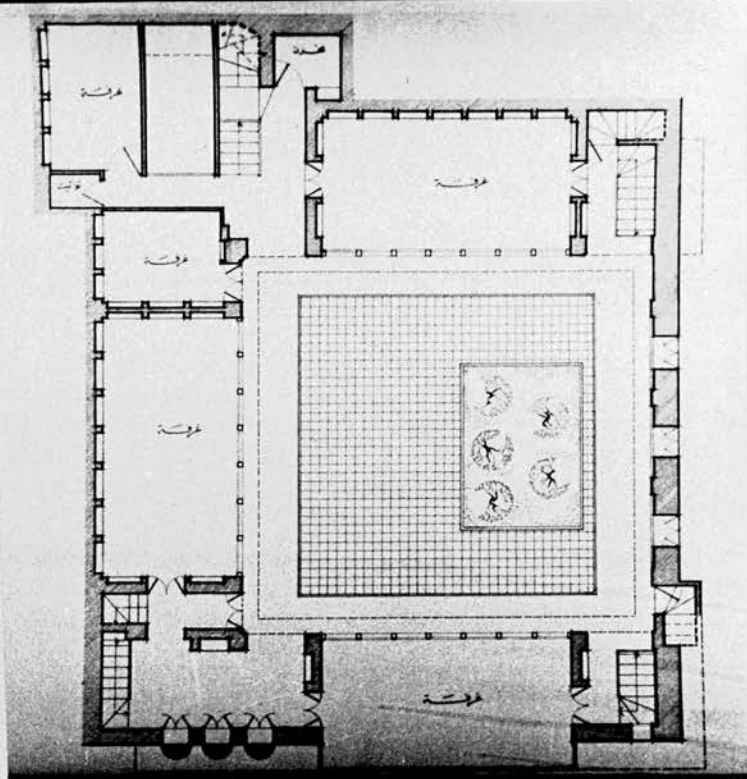
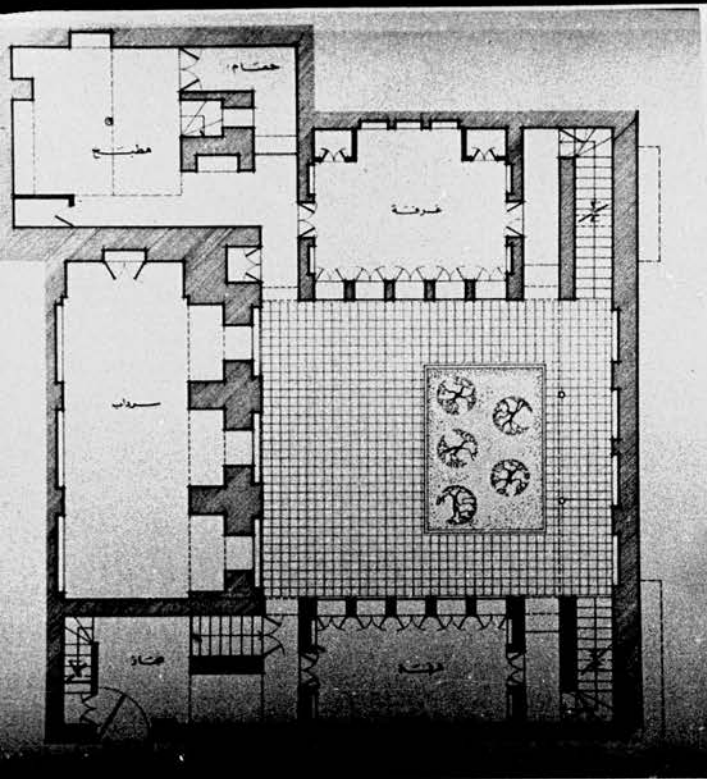


Fig. (AVI.3)

Plans and elevation of a Baghdad courtyard house.

(Drawings prepared by students of School of Arch., Univ. of Baghdad)

very discriminating manner. The bulk of the building is usually a heavy mass of solid bare bricks with few openings to the street at ground floor level. Off this mass, at first floor level and in sharp contrast to the solid matter form projects out a light, fine wooden structure cantilevering for about one metre and supported by wooden corbels (Fig. A VI.3). The shell of this mass is actually a row of windows of standard dimensions and design peculiar to the house itself or to a row of houses.

Given protection from the sun by the narrowness of the street, the mason seems to have used a fair amount of freedom in providing external windows along the facade at first floor level. These windows are some of the most delicate and intricate elements of the house. They are usually based on the repetition of one standard bay of a width of about one metre. The window glass is divided into small panels held in place by wooden frames. The shading devices used are louvered or arabesque wooden panels which usually slide open vertically. A section of the window bay (Fig. A VI.4) shows that these devices are placed between the glazed panels from the inside and a set of iron bars on the outside, which function as an anti theft device.

The structure of the roof is made up of wooden beams carrying a layer of mats topped by 30 cm thickness of a mixture of mud and straw. This construction provides a considerable amount of thermal



Fig. (AVI.4)

Windows and shading devices.

Materials used are wood for the structure, window frame and shading devices, iron bars for security, and glass panels.

capacity, but is unlikely to provide adequate thermal resistance. The inside surface of the roof structure is sometimes covered with wooden panels of a high level of ornamentation. The floors of the rooms are brick or stone tiles whereas the CY and the serdab are usually paved with clay tiles which serve a good thermal function in the summer when they are sprinkled with water. Being porous, they absorb the water and provide for an evaporative process which helps in attaining a more comfortable environment.

In order to have a complete description of the house, a reference to its typical column must be made. This is a slender wooden column which usually supports the balcony in the courtyard. It has a hexagonal or octagonal section and a capital of a complicated decorative geometry which expresses a transition to the square abacus. The design of the column and the construction of the capital, which is basically small carved pieces of wood nailed together, expresses economy in the use of the material (Krunic, 1960).

2.1 The Spacial Concept

In spite of the Persian and Turkish architectural influences on the evolution of the CY house, its original concept remains unchanged. A change in its size reflects the social standing of its occupants. This generally does not mean a break in the urban uniformity of a height of two storeys, neither does

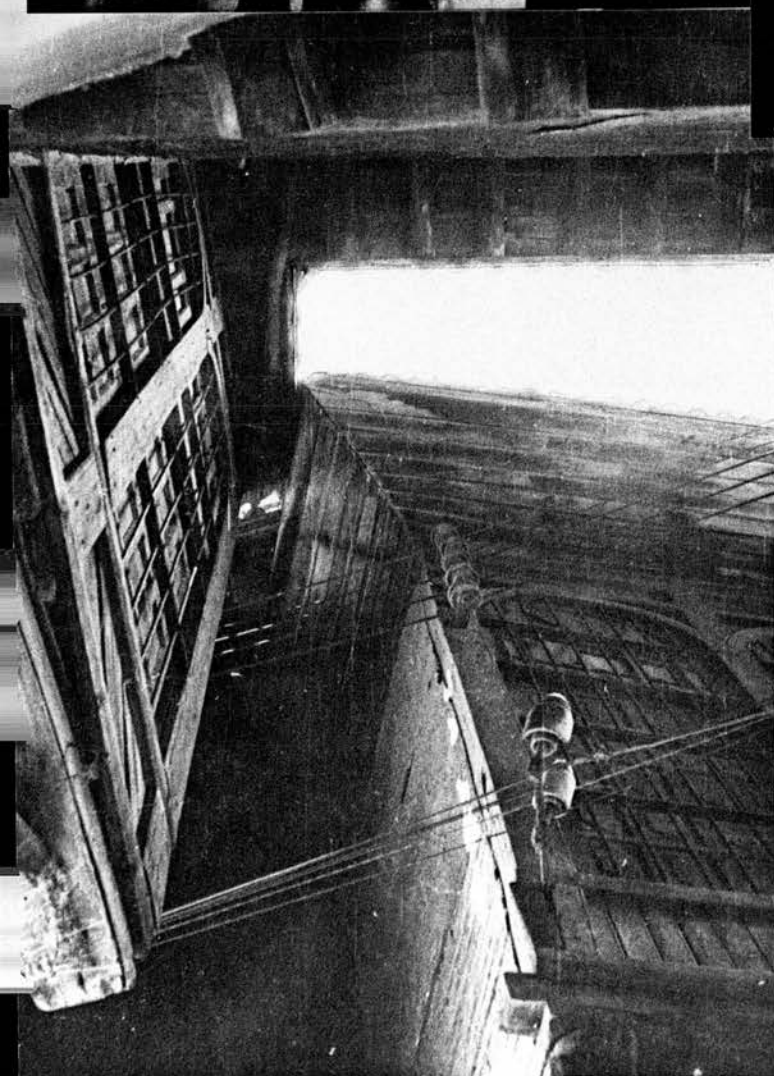
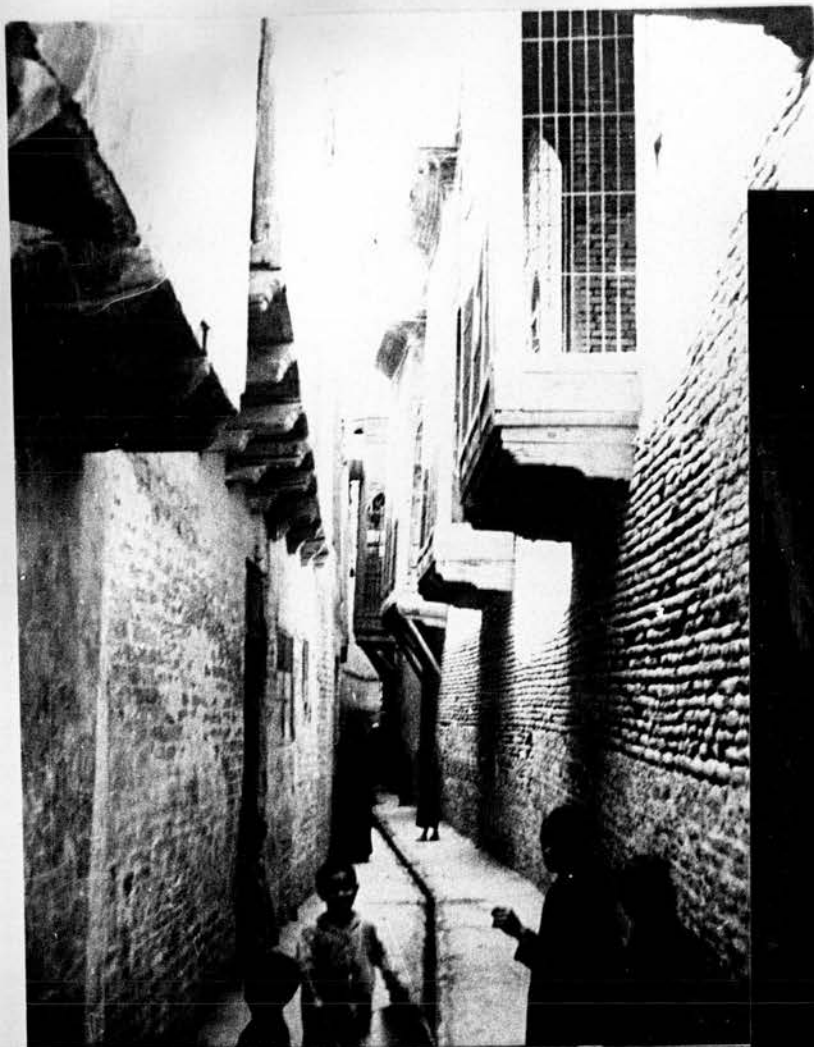


Fig. (AVI.5)

A pedestrian's view in the alleyways of the old city of Baghdad.

90 - 100 cm. projections at first floor level protect the narrow walkway from the high altitude sun.

it imply a radical change in the size of the CY. A house which reflects wealth and upper social standing is constructed around several successive CYs of differing classifications, such as reception of guests, and the harem which acts as the family private quarters, and the servants (Makkia, 1969). And thus the residential old city developed as a monolithic layer of mainly two storey houses showing what seems to be uniformly dense and compact planning throughout. This can be understood as a shelter from the very intense sun of the hot dry climate of the city, (Fig. A VI.5)

One of the important qualities of the CY houses is the variety of spaces they contain and the range of functions a space can have. The spaces vary by both their extent of shelter and location. Their specific functions and times of use, as related to the day or season, reflect a suitability of the concept to the widely fluctuating climatic conditions of the city. These spaces vary between the roof which is completely open to the sky and the serdab, which is sunk in the ground (Fig. A VI.6)

The general spacial concept, which is of an inward looking house, reflects the individual-family-community relationship in the city. The privacy of the house from the street is very well demonstrated by the design of the main entrance which is usually through two doors separated by a transitional space.

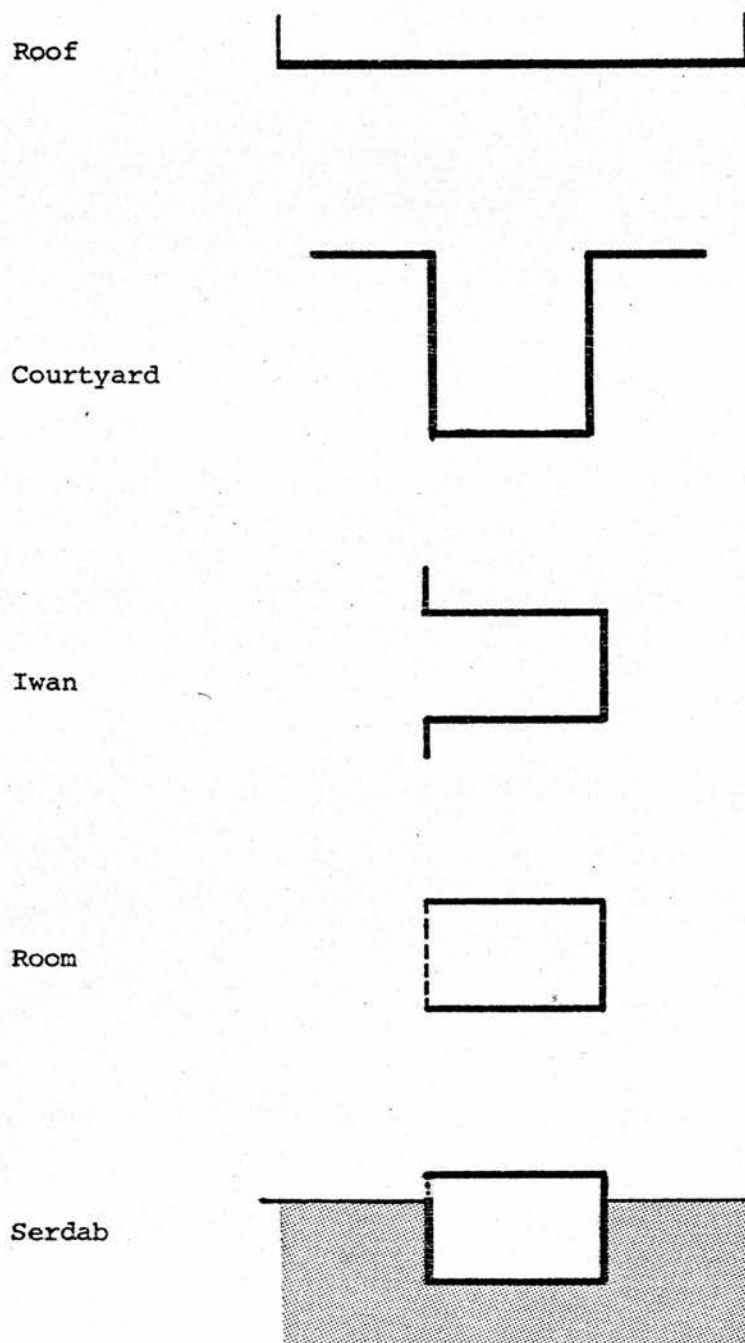


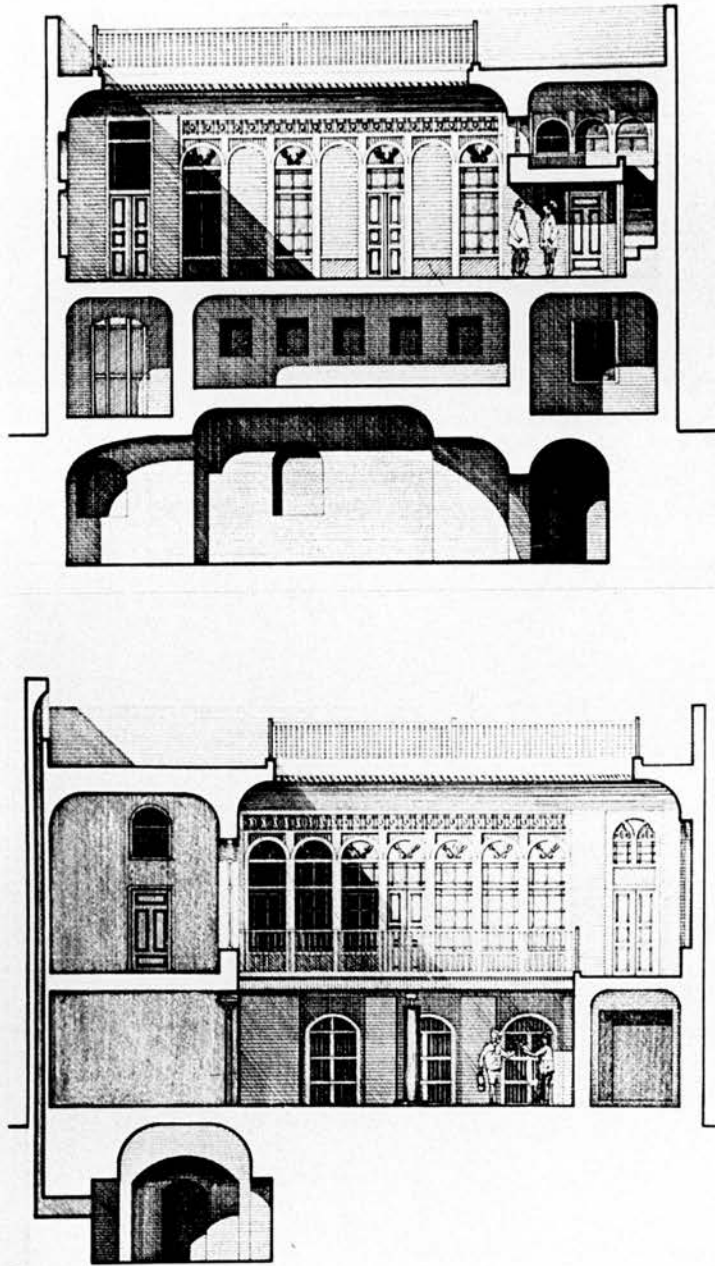
Fig. A VI.6

The space variety in the courtyard house

The inside door leads to the CY and is perpendicular in orientation to the street door. This extreme concern for privacy of the family within the community is not paralleled by that of the individual within the family. Evidence for this can be taken in the arrangement of the rooms and their openings around the CY and the communal functions of some of the spaces like summer night sleeping on the roof.

The flat roof, forms a ring around the CY and is surrounded by walls high enough to ensure privacy from the similar level neighbouring roofs. The uniformity in height of the roofs ensures maximum exposure to the sky and encourages the movement of the air which helps in the summer nights to create a pleasant environment. This, compared with the undesirable effect of the long-wave radiation from massive elements inside the rooms is the reason behind summer night sleeping on the roof. Another function of the roof, which is continuous throughout the year, is the hanging of the washing.

The other space in the house which is open to the sky is the CY. It is, however, well protected from the sun by the surrounding rooms and balconies. This helps in making the environment of the space more hospitable in the summer days when it becomes the centre of activities. The importance of the CY is in being an element which allows for one of the basic



2. 2. 2.

Fig. (AVI.7)

Two sections in a house typical of the courtyard houses of Baghdad.

The privacy, security and environmental shelter provided by the courtyard are unparalleled by those of any open spaces provided by the European type house.

characteristics of the urban pattern, that of small or narrow street spaces by providing an alternative "breathing space" for each house. The CY also plays a vital role in regulating the thermal environment of the house which will be discussed later.

The activities of the CY are frequently extended to another space, the iwan. This can be described as a ground or first floor room which is completely open from one of its sides to the CY. The upper iwan replaces the CY in winter by accommodating for family life. In general, the iwan is used for a wide variety of functions. It is used for lunch, afternoon tea, summer siestas in the absence of a serdab and night sleep during spring and autumn seasons. In this respect it serves as a transitional space between the roof and the rooms, which accommodate for winter sleeping (Fig. A VI.8).

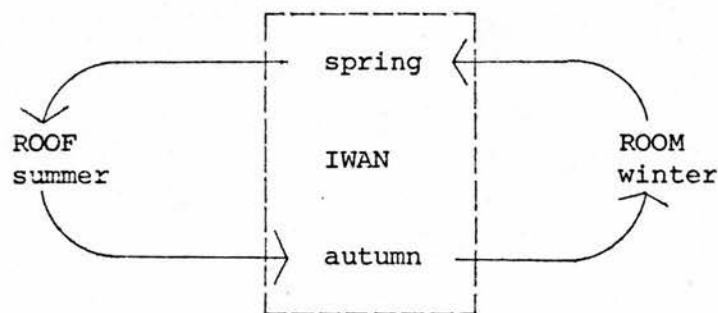


Fig. A VI.8 The cycle of change of night sleeping space during the four seasons.

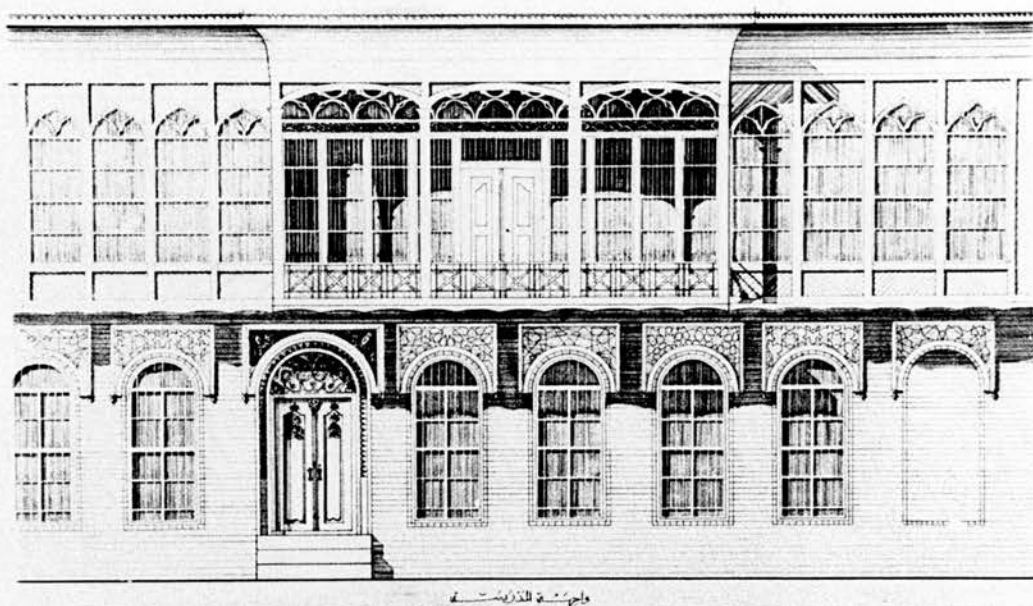
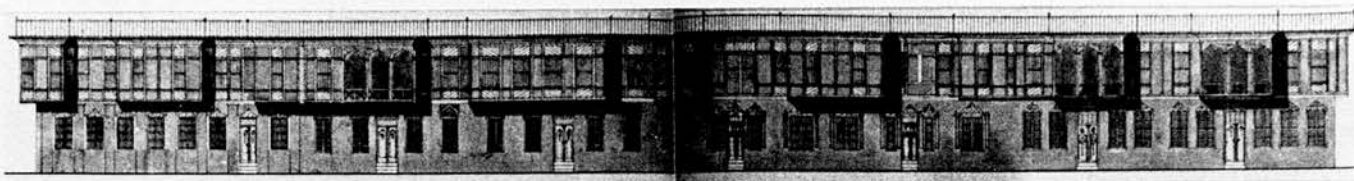


Fig. (AVI.9)

Top: Elevation of a complete block of the old city. Due to the character of the urban spaces, these elevations can not be seen as one unit, where a form of standardization is evident.

Bottom: Elevation of a courtyard school - same proportions and planning principle as the courtyard house. Roofing technique is by use of iron beams and brick jackarching.

These elevations express buildings of a more recent era. Evidence to this is the roofing method and the introduction of elements foreign to the traditional house: but the basic concept remains the same.

The Arab tradition of hospitality is reflected in the distribution of closed spaces to function, where some of the most spacious rooms are usually reserved for guests. These spaces are accessible with no circulation interference with the rest of the house. Krunic (1960) divided the CY house into two sections, the "harem" for family life, and the "selamluke" for receiving and entertaining guests. Otherwise, the functions of the individual rooms are less defined than other types of houses.

The last of the spaces is the serdab. This can be one or a series of rooms sunk in the ground to various degrees and linked with the rest of the house by a special staircase. Natural light is usually provided through small openings the sizes of which are determined by the difference in level between the serdab's ceiling and the CY's floor. These spaces, well sheltered from the summer sun, and having the advantage of the considerable thermal capacity of the surrounding earth, provide what seems to be the ideal naturally conditioned thermal environment in the summer afternoons, when they are used for siestas.

Ventilation is provided for the serdab by means of a special vertical duct system in the peripheral wall, the "badgir". The function of this is to capture the air flowing from the

north-west, which is generally prevalent wind, by an opening at parapet height at the roof facing that direction. The air is then streamed down through the duct to an opening in the side of the serdab. In some cases the bottom of the duct is carved below ground level creating a small ditch for water. Therefore, by an evaporative process, the passing outside air is cooled and humidified. Alternatively, a porous pottery water container is placed in the path of the air as it enters the serdab (Fig. A VI.10).

The above description of the spacial concept of the house clarifies its adaptability in providing for the occupants' needs in the widely fluctuating climatic conditions of the city. The internal thermal environment of the house is influenced by its geometrical concept.

2.2 The Thermal Logic of the Geometry

Studying the geometrical concept of the house from a thermal point of view is of special concern to this thesis since it demonstrates the evolution of a logical idea which takes advantage of the behavioural characteristics of the climatic elements, as well as the thermal qualities of the elements of the building, in bringing the internal environment nearer to comfort.

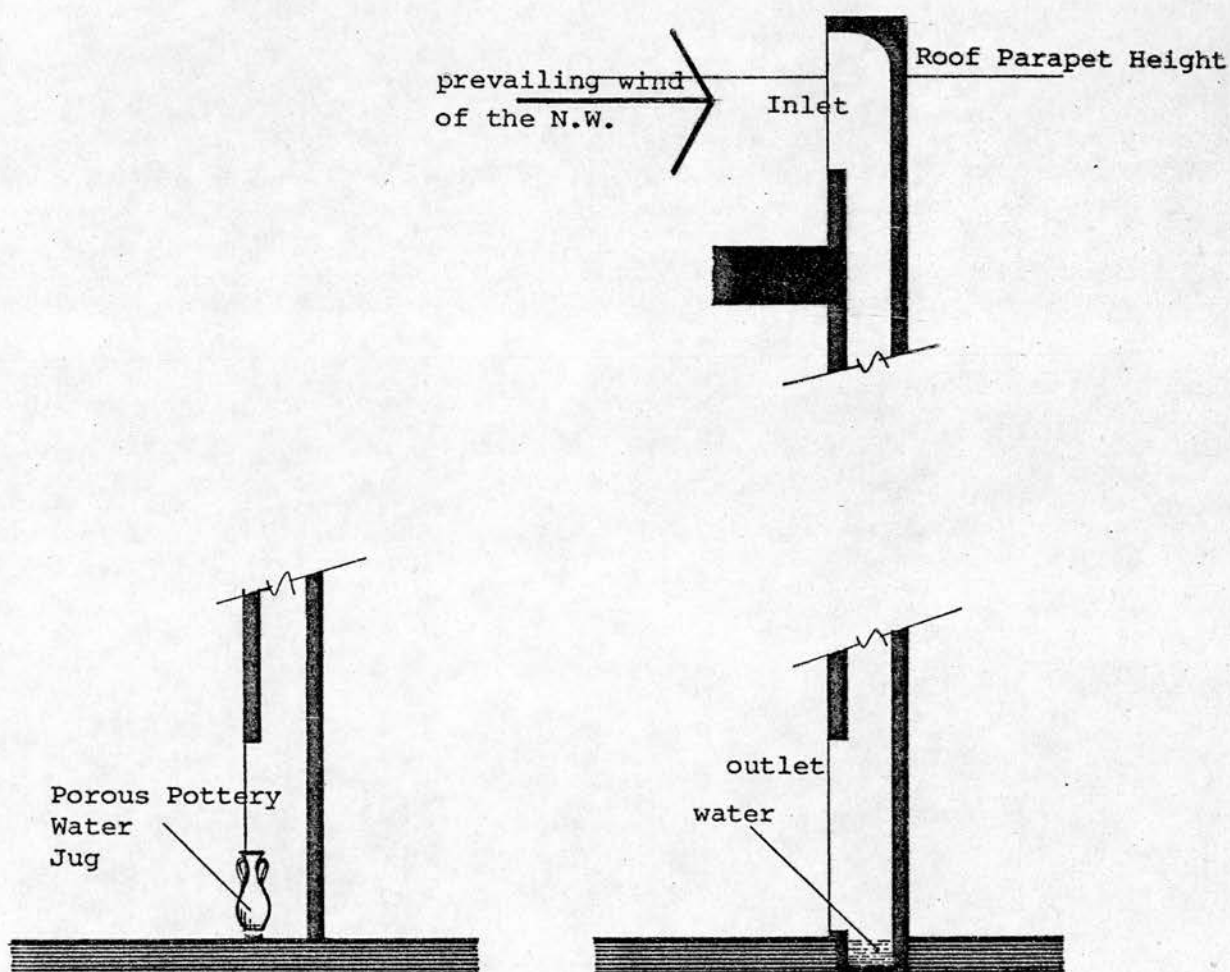


Fig.A VI.10

The Badgir.

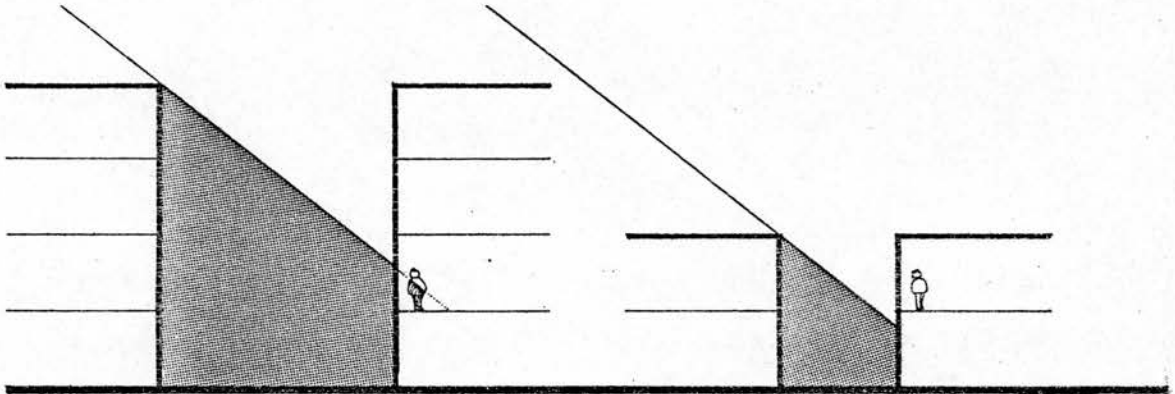
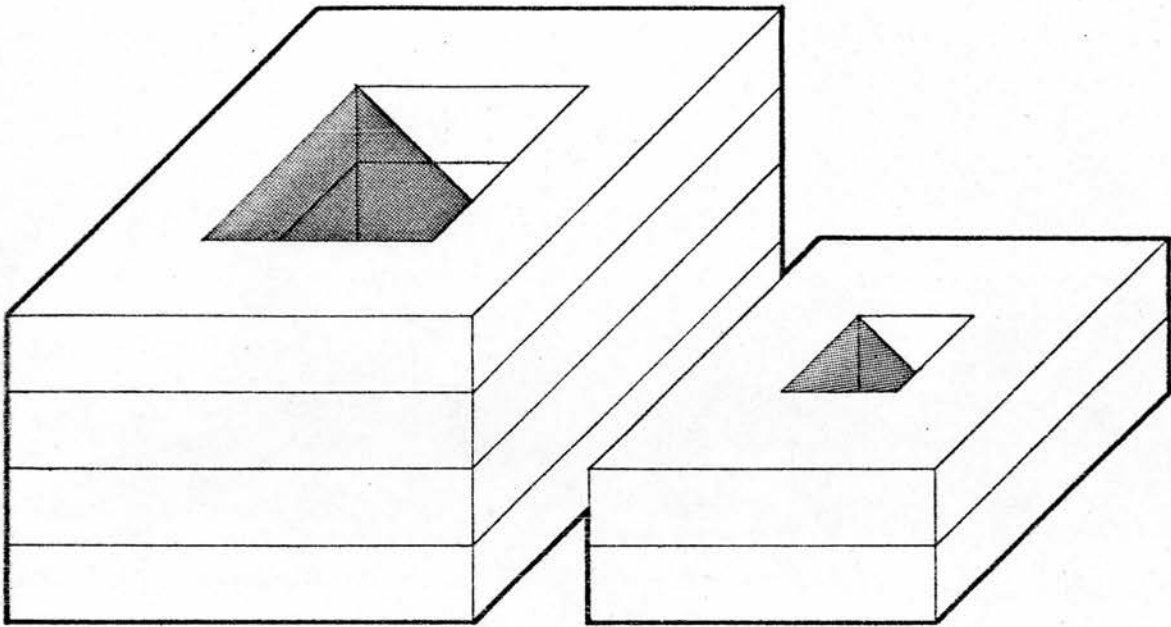
Humidification and cooling of the air is provided by one of two alternatives, water at the bottom of the shaft or a water jug at the outlet.

The existence of the CY is detrimental to both the concept of the house and the urban character. The discussion here starts by a study of the geometrical implications of the CY.

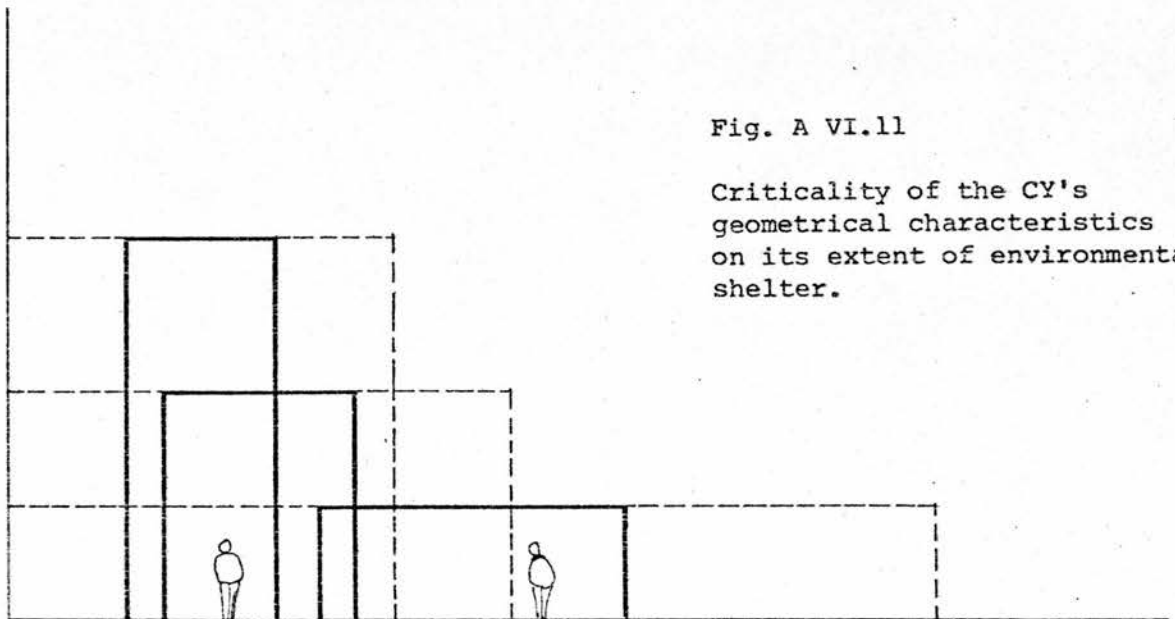
2.2.1 The Criticality of the CY's Geometry

The size and proportions of the CY are the two geometrical parameters responsible for the extent of exposure of the CY facades to the sun. Their influence, however, is of an interesting diversity which is worth exploring. For this purpose we consider the effect of change of either of these parameters. The proportions of the CY determine the ratio of shaded to insulated areas within it irrespective of its size. This, however, does not imply that two CYs with similar proportions but differing sizes provide similar shelter to the internal facades, since the size of a CY affects its relation to man and doors and windows in its facades. To explain this effect we consider a window in a courtyard facade at ground level. Assuming that its level is not changed, the window receives less sunshine when the CY adopts a larger size. On the other hand, a change in proportions has some obvious effects on the extent of shelter the CY provides (Fig. A VI.11).

Building on observation, it is possible to state that the CYs of the existing houses in Baghdad are within reasonably limited



Effect of change in size



Effect of change in proportions

Fig. A VI.11

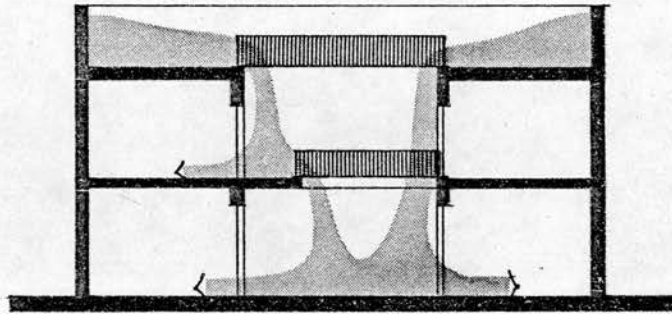
Criticality of the CY's geometrical characteristics on its extent of environmental shelter.

variation in geometrical properties. Building on this, and as a conclusion to the above analysis, one can state that the CY had adopted critical values of size and proportions which are dictated by the geometry of the solar trajectories and the possible effect on the microclimate of the individual spaces of the house.

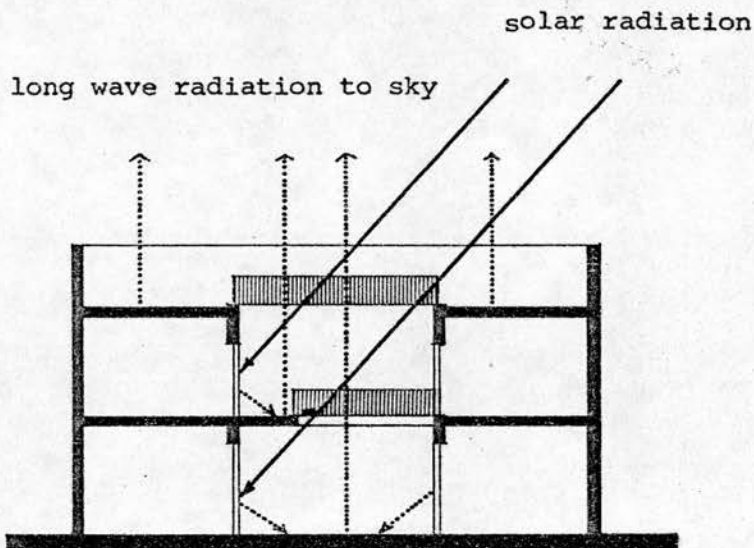
A CY which is defined in size and proportions can only gather around it a definite number of rooms and consequently determines the size and proportions of the whole house.

2.2.2 The Thermal Exchange Mechanism

Owing to the geometry of the house, processes of natural thermal conditioning occur. They can be classified into two types, convectional and radiative. The convectional process is a night time one. It occurs when the horizontal surface of the roof, being well exposed to the sky, continues to lose heat to it by long wave radiation. This, in absence of the sun, causes a net radiative heat loss by the surface and consequently a drop in its temperature and therefore the temperature of a layer of air close to it. Being heavier than that contained by the CY, this cold air spills onto the balcony of the first floor and the floor of the CY, which are of higher temperatures than the roof. And thus convective cooling continues throughout the night (Fig. A VI.12).



The convective cooling by descending cold air from the roof into the courtyard



The radiative heat exchange in the courtyard. The high thermal capacity floor of the courtyard, being well shaded from the sun, and having a good exposure to the sky, acts as a good mediator in long wave radiative heat exchange between the facades of the courtyard and the sky.

Fig. A VI.12

The natural thermal conditioning of the house due to its geometrical characteristics.

In the radiative process the key element is the floor of the CY. Having the high thermal capacity of the underlying earth and being exposed to the zenith and sheltered from the sun, the CY's floor acts as an intermediary in a radiative heat exchange between the CY walls and the sky in a cooling process of the elements of the house. The two thermal conditioning processes act together in cooling the house and have desirable effects during the long, hot part of the year. But their occurrence in winter, and the fact that the house is well sheltered from the sun, act together in creating an uncomfortably cold environment on the ground floor, which is almost abandoned in this period of the year.

And thus the CY house of Baghdad is a remarkable concept for a shelter in the predominantly hot climate of the city, and a bold architectural statement reflecting the social background in which it evolved. This background, however, is experiencing a major change which is reflected on the modern architecture of the city.

The CY house, which can be described as rooms surrounding a central open space, can be taken as one of two extreme concepts of an urban setting. The other extreme being the so-called modern type house, which is a cluster of rooms surrounded by open space. This second type of house typifies the modern

trend in the residential architecture of the city.

The change in the concept of the house can be attributed to socio-cultural factors, but the radicality of the change can only indicate a failure to develop the traditional concept in order to allow for the occurring changes. It remains to the researcher to compare the two houses and evaluate their performances considering them as alternative attempts to solve an architectural problem. To this end the Insolation Index and Table (Chapter VI, page VI.33) provide a method of comparative evaluation of forms from a climatic point of view.

Although the Insolation Index is devised for forms the elements of which do not shade one another, it can be used for more complicated ones by making some simplifying assumptions which do not affect their insolation values. The insulated parts of the courtyard house are its roof, CY and street elevation. From Appendix VII it can be seen that the insolation of the CY is equal to that of a hypothetical roof sheltering it. Similarly, it can be assumed that a hypothetical horizontal roof over the narrow street stretching along the front elevation, receives equal insolation to the elevation itself.

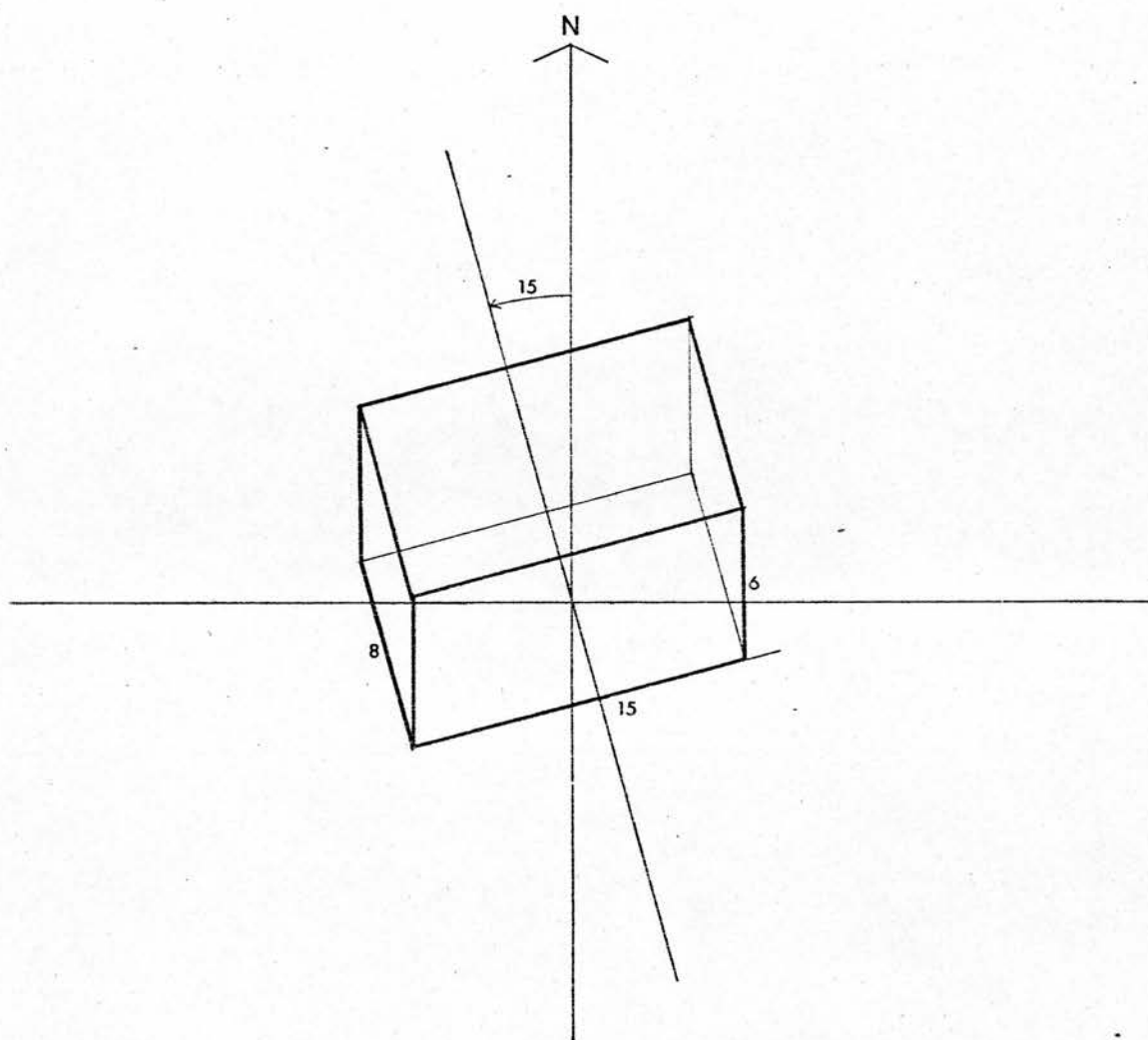
As examples, two forms are here considered to represent the two concepts, the courtyard and the modern type house. Floor

areas are taken to be equal, with each form having 240 sq. m. on two levels. The dimensions of the courtyard house are chosen as typical of this type of house. Its orientation in these calculations is immaterial, since three of its external sides are sheltered by neighbouring houses and the street elevation by the fairly close opposite houses. Moreover, the insolation of the courtyard is calculated by a substitution by a horizontal surface, which is indifferent to orientation.

The form representative of a modern type house is given a height of 6 metres, i.e. two storeys, and plan rectangular dimensions of 8 x 15 metres. The long facade of the form is given the orientation of E. 75° .S. These geometrical characteristics ensured a similar total floor area to the CY house example. The proportions and orientation are chosen to be favourable, i.e. less insolation, by consultation of the insolation index.

Figs. A VI. 13-14 show the calculations of the insolation numbers of the two types. By comparing these two numbers it is possible to conclude that the CY house receives an amount of over-21 radiation which is approximately 15% less than that received by the modern type example. And therefore from this

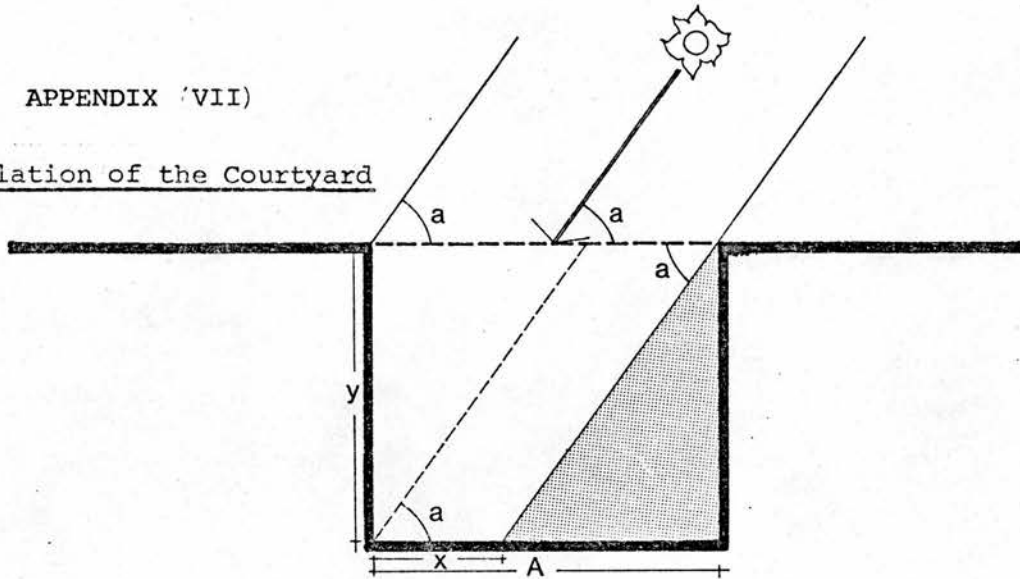
point of view, the traditional type is superior to the modern one, even when the geometry of the latter is chosen to be climatically favourable.



SURFACE		AREA	INS.NO.	
azimuth	slope	A	YI	A YI
	0	120	59	7080
75	90	48	15	720
165	90	90	26	2340
255	90	48	35	1680
345	90	90	6	540
FORM INSOLATION NO. —————→				Sum 12360

Fig. A VI.14

APPENDIX (VII)

Insolation of the Courtyard

$$i) \quad \text{Ins. of "cover"} = I \cdot \sin a \cdot A$$

$$ii) \quad \text{Ins. of "C.Y."} = I \cdot \cos a \cdot y + I \cdot \sin a \cdot x$$

$$\text{BUT: } x + y \cdot \cot a = A$$

$$\therefore A = x + y \cdot \cos a / \sin a$$

$$y \cdot \cos a = A \cdot \sin a - x \cdot \sin a$$

$$\therefore \text{Ins. of "C.Y."} = I (A \cdot \sin a - x \cdot \sin a) + I \cdot x \cdot \sin a$$

$$= I \cdot \sin a \cdot A$$

\therefore The insolation of an enclosed courtyard is equal to the insolation of its hypothetical horizontal lid.

APPENDIX VIII

Climate of Baghdad

In studying the climate of Baghdad and its determinant factors, one would have to form an idea of the geographical setting of the area and its surroundings as well as the climatic implications in both the macro and local scales.

Summarized information on these is scanty, and only few sources have been interested in its collection and publication. One example is a report of Polservice Consulting Engineers on the master plan of Baghdad (Polservice Consulting Engineers, 1967). Another important source of climatic information and data is the Meteorological Station of the Airport of Baghdad. This station supplies processed data made from observations over a period of around thirty years.

It is mainly by reference to the two sources mentioned above that the following study was made.

1. The Geographical Setting of the City and its Region

The city of Baghdad, the capital of Iraq, is situated between the latitudes of 33.4 and 33.5 degrees north, and on the longitude of 44.5 degrees east.

The Mesopotamian plains, the north part of which contain Baghdad, is a broad synclinal depression at the foot of the Zagros mountains. Foothills separate these mountains from the north and northeast fringes of the plains (see Fig. A VIII.1). The plains are also surrounded by the northern and southern desert plateaux from the west and southwest, and by the Jezira plain from the north west.

Four main regions differing in their geological structure and morphology form the main part of the plains. The first region is that of the north which ends around 30 kilometres north of Baghdad. It is of pleistocenic alluvial terraces. The second is the Mesopotamian Flood Plain which contains Baghdad in its centre. South of this is the third, Mesopotamian Delta Plain, and the fourth is the littoral region Marshes and Estuary which is situated furthest south.

The depression is filled by alluvial deposits thus forming a very flat plain of a 102,000 sq. Km. area, with a small altitude above

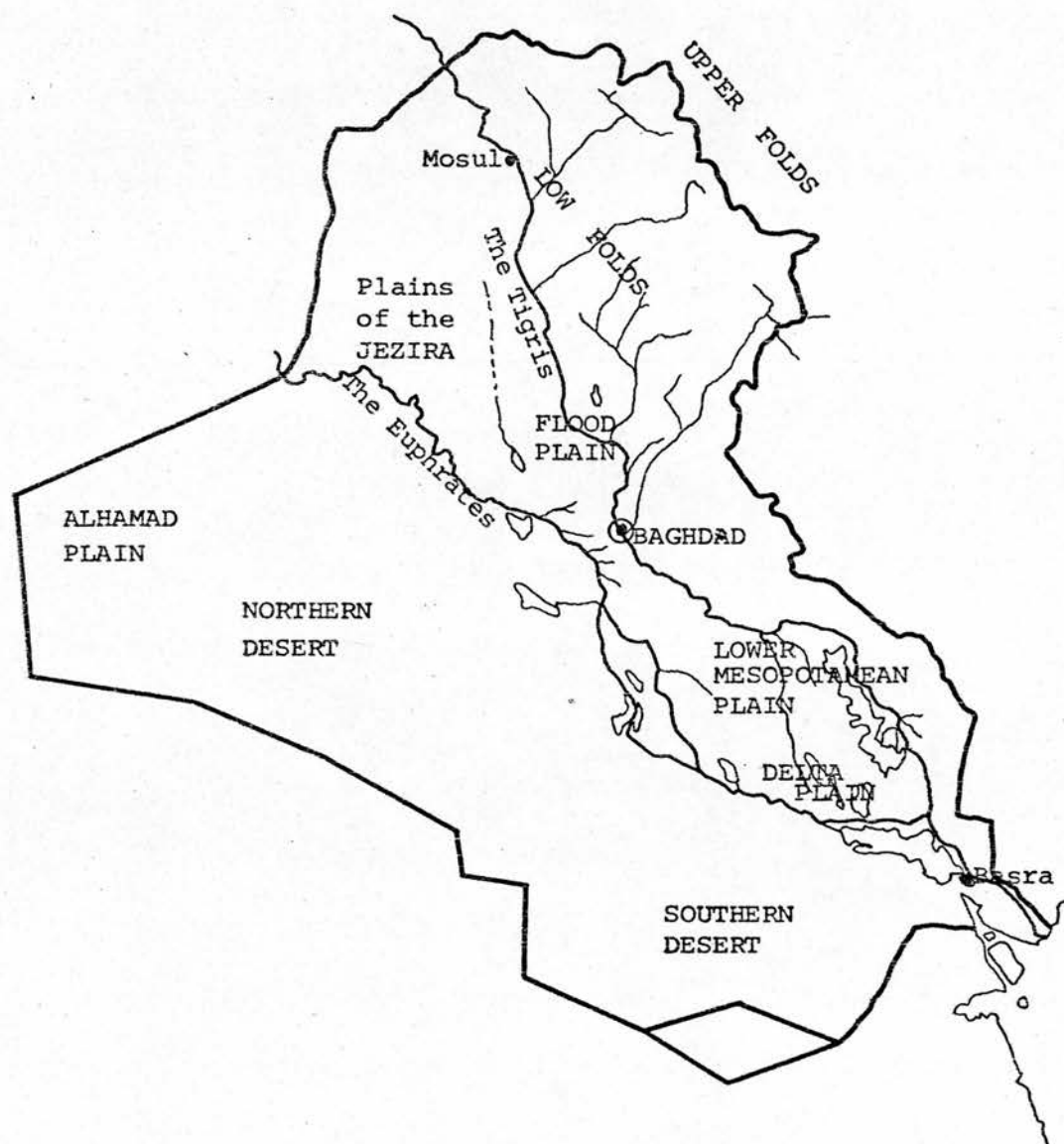


Fig. A VIII.1

The Geographical Setting of the City of Baghdad and its Region

sea level. The slope of the terrain changes from an average of 10 cm/km in the northeast to 1.5 cm/km near the Gulf. The plain is fed by two major rivers, the Tigris and the Euphrates. These rivers, together with their tributaries, carry from the mountainous terrains what amounts to up to 70×10^9 cubic metres of water yearly.

2. Climatic Regional Evaluation

In climatic terms, the Mesopotamian Plain is shared between the tropical continental climatic zone and the subtropical mainland climatic zone. Accordingly, the winter temperatures are relatively low, but very seldom fall to a level below zero degrees centigrade. Summer temperatures are comparable to those of tropical areas.

Baghdad, being situated in the middle of the Flood Plain, has no distinctly different local climatic features from the area around it. The influence of the proximity of the two rivers is limited to the local climate of their narrow shores. A study of the climate of the Flood Plain can therefore help to understand that of the city. It can be described as having two main seasons, hot and cool, and two short periods of transitional character.

An almost continuous movement of air from the northwest occurs during the long hot part of the year. This is caused by an area

of stabilized low pressure over the Asiatic Continent, with its centre over the Himalayas, and the Azores region of high pressure. This air, passing by the mountainous shores of the Mediterranean and the Zagros Mountains, is deprived of humidity as it moves towards the Gulf passing by the Mesopotamian Lowland, thus causing almost continuously cloudless weather.

The picture changes during the cool part of the year; the Azores centre of high pressure is weakened whereas a high pressure area forms over the Asiatic Continent. This influences the climatic stability and causes an increase of humid winds from the south of the plain deviating to southwest and southeast. This wind causes cloud covers and slight showers of periodic characteristics as well as violent storms. Strong winds or air whirls passing over very dry areas of silty desert cause the dust storms which are a marked feature of the climate of the plain.

3. Climate of the City of Baghdad

Owing to the situation of the town on a wide and uninterrupted flat open plain, one finds little variation of its climate from that of the rest of the plain. The effect of the river Tigris is limited to areas within its immediate vicinity, where a cooler breeze is felt, especially in the spring ^ttime, when the river water rises and

t?

spreads broadly, and the temperature of the water is low.

Figs. A VIII.2-11 are diagrams giving the important features of the climate. They are based on data supplied by the Meteorological Station at the Airport of Baghdad, which are the results of observations made in the years 1941-1970, except in the case of radiation where observations only go back to 1967.

3.1 Air Temperature

The daily fluctuation of air temperature reaches a minimum at 0600 hours and a maximum at 1500 hours. The amplitude is smallest in January at 11.5°C and extends to a value of 18.8°C in September. The normal range of air temperature in the complete year is of the value of 40°C . This range lies between a normal minimum of about 4°C at 0600 hours in the 4th to 10th days of January, and a normal maximum of 44°C at 1500 hours in the last four days of July. The absolute maximum and minimum were registered to have been 50.2°C and -8.5°C in August and January respectively.

Normally, December, January and February average hourly temperatures are all below 21°C , whereas the last week in May, the full months of June, July and August, and the first half

of September, fall completely above the 21°C level. The temperature exceeds the value of 28°C , which is the upper limit for comfort in Baghdad (see Chapter IV), in 206 days of the year; and in no day of the year does the full range of air temperature fall fully within the comfort range.

3.2 Humidity

Relative humidity values are low. The yearly average is 43%. The fluctuation of the relative humidity is of similar character to that of the air temperature. The monthly averages vary between a minimum of 22% in June to a maximum of 71% in December and January. The daily amplitude is of considerable magnitude. The highest daily value occurs at ⁰⁶⁰⁰1500 hours and the lowest at ¹⁵⁰⁰0600 hours. The relative humidity ranges between 52% and 89% in a January day, and between 12% and 32% in a July day. X

The vapour pressure, which is indicative of the behaviour of both temperature and humidity, varies between an average of 6.5 mm Hg in February and 9.5 mm Hg in August. The minimum value on a winter day can be $5\frac{1}{2}$ mm Hg. This shows that humidification is a greater requirement during the winter than it is during the summer (see Appendix IV).

3.3 Clouds

Clouds in Baghdad are mostly over 2500 m, and cloud cover is small. For the normal daily totals, the maximum is 3.5 Oktas. It occurs in April. The values of the four summer months, i.e. June to September, are less than 0.5 Oktas with August having the lowest value of 0.2 Oktas.

3.4 Rain

The cloud cover condition mentioned above is indicative of the rainfall. The mean yearly total is 146.4 mm. The four summer months are almost completely deprived of rain. The maximum rainfall in one day was recorded to be 71 mm. Precipitation during the cold season is usually violent but brief.

3.5 Radiation

Baghdad receives a great amount of solar radiation throughout the year. The total for a day in June, where a horizontal surface receives 80% of the possible sunshine, is 30×10^3 KJ/m².day. The high value of sunshine duration is characteristic of all the months of the year, the minimum occurring

on a January day where the actual duration is 61% of the possible sunshine, and where solar radiation totals 11×10^3 KJ/m².day.

3.6 Storms and Dust Storms

July is the month with the highest frequency of sand and dust storms, but they take place in every month of the year and cause a considerable amount of irritation. On average these storms occur on 20 days of the year. July and December/January are the months when the minimum and maximum barometric pressures occur respectively.

3.7 Wind

The most frequent and prevailing winds arrive from the north-west in all months of the year, with deviations to the north and west in July. In January, winds often come from the north and southeast. Calms are seldom in Baghdad; they amount to 4% of the time in July and 8% in January.

North winds of cool air from the mountains start to increase at 0900 hours in July. They have a high frequency in August

starting at about 0600 hours. In September, their frequency equals that of the northwest, and at 1500 hours in October and November the north wind is even more frequent than the northwestern. Undesirable west winds become of a higher frequency in the afternoon hours. They bring hot desert air at this usually overheated part of the day. Higher velocity winds of 8.5 - 9.5 m/sec. mostly occur from the north, north-west and east-southeast directions. The highest wind speeds occur in March, and lowest in October.

From the above, it is apparent that the only favourable climatic factor which could be directly exploited in architectural design and town planning, is the almost uninterrupted, moderate dry, northwestern and northern winds. These winds can be used to moderate the thermal conditions in the town as well as in the house itself.

On the other hand, unfavourable factors can be traced in almost every element of the climate. These are the large daily and annual deviations in air temperature from the comfortable conditions, the intense radiation of the sun in the overheated summer, the low humidity, the dust storms and the afternoon desert wind from the west.

The following diagrams express the properties of the elements of

the climate of Baghdad. The solar chart was prepared by the Building Research Centre in Baghdad. The other diagrams are based on data supplied by the Meteorological Station of the Airport of Baghdad.

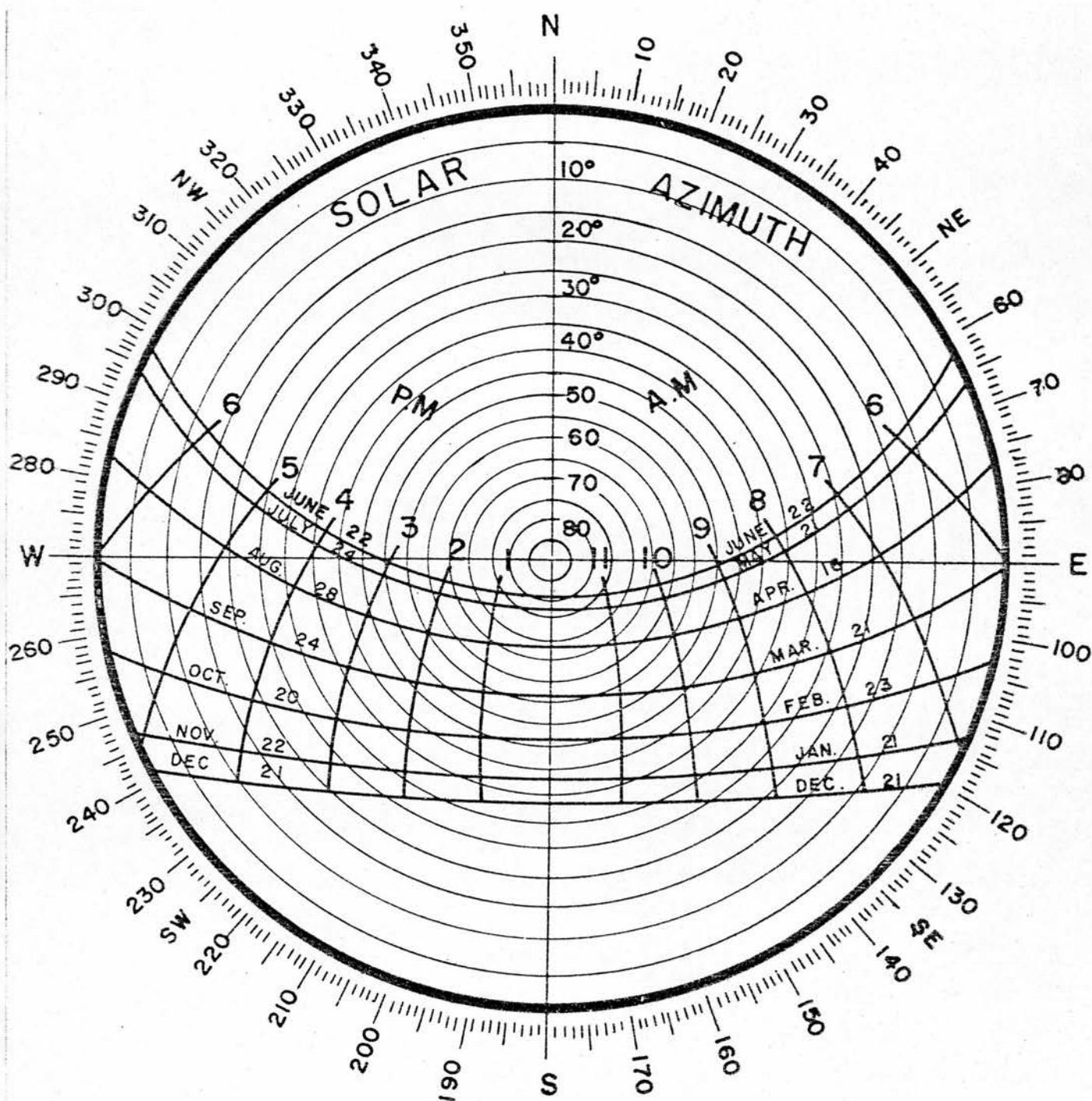


Fig. A VIII.2

The solar chart for Baghdad (latitude 33°N) as prepared by the Building Research Centre (Baghdad)

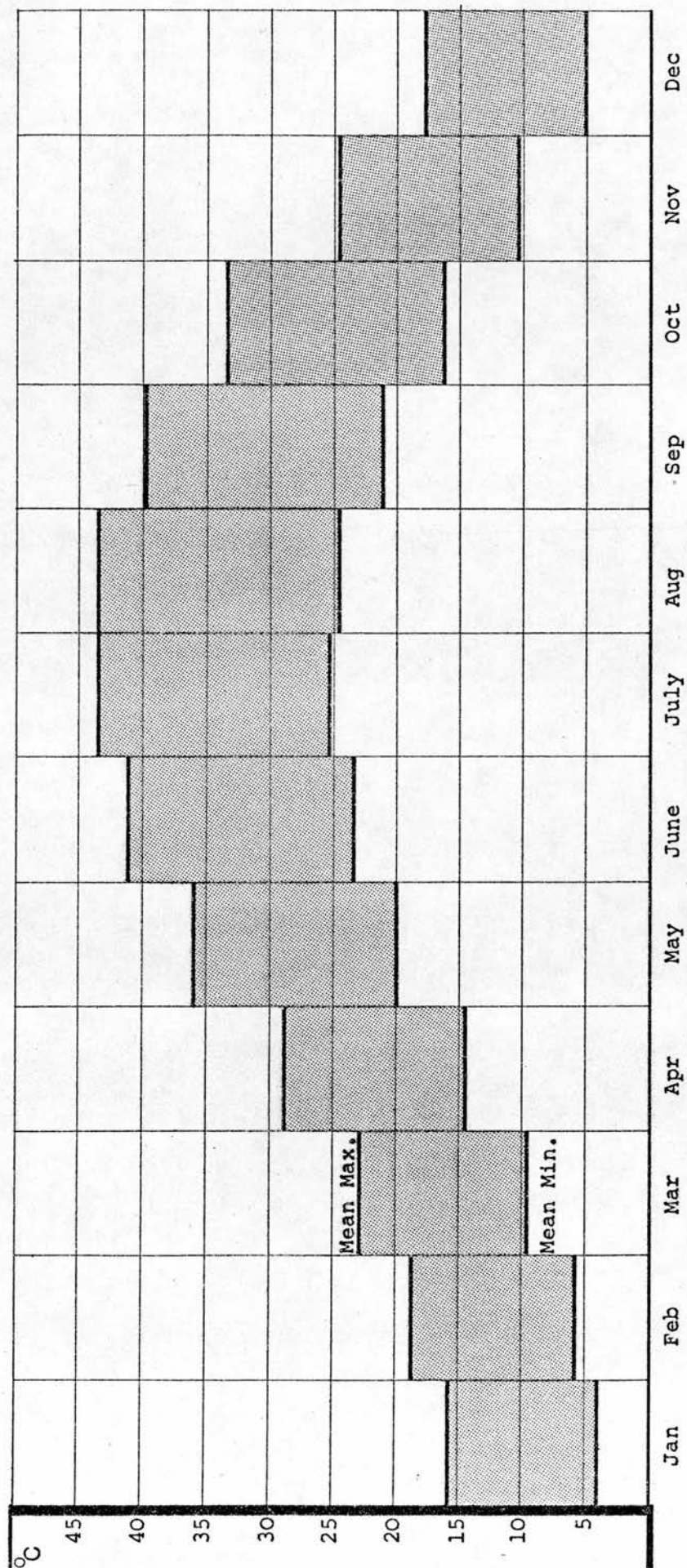


Fig. AVIII.3

Monthly Mean Maximum and Minimum Air Temperature

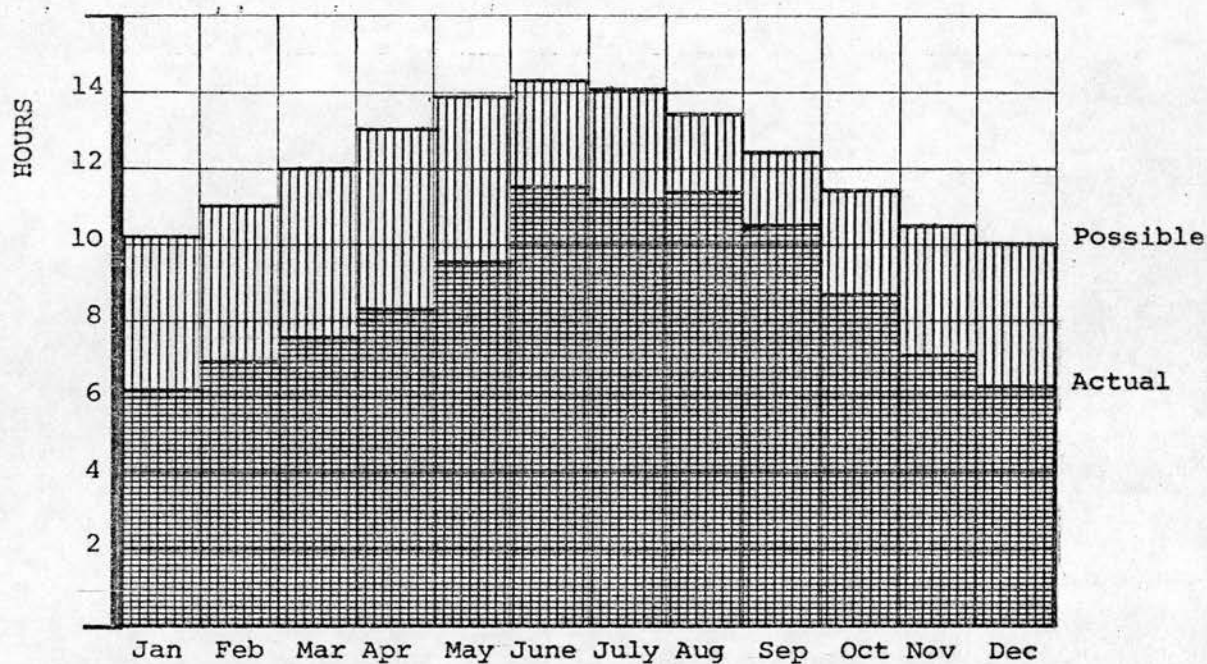


Fig. AVIII.4
Monthly mean daily possible and actual duration of sunshine

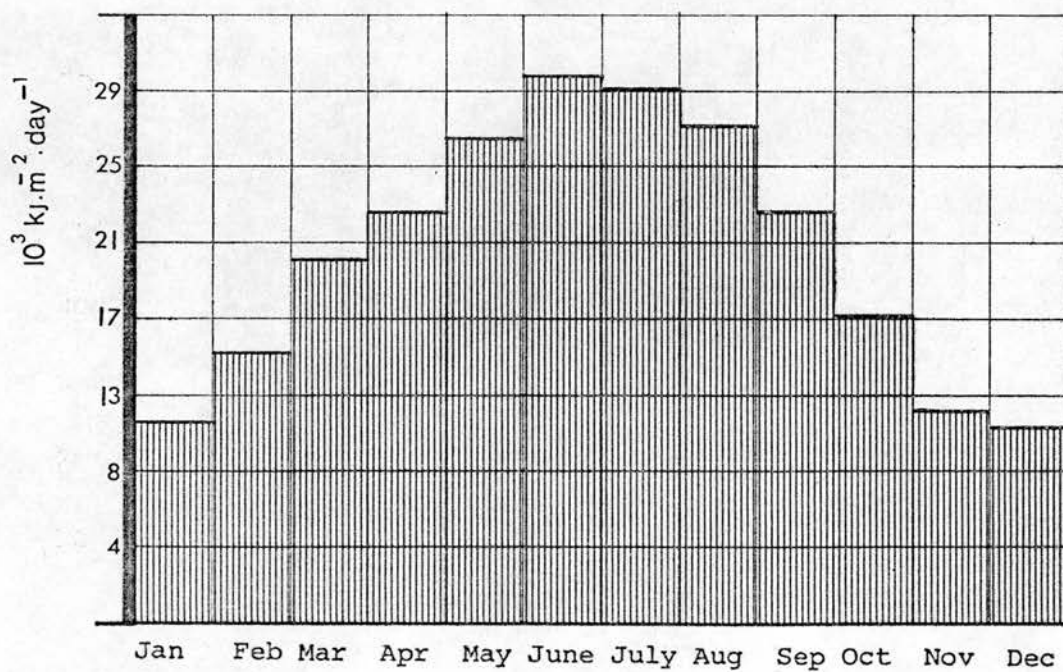


Fig. AVIII.5
Monthly mean daily total incoming radiation

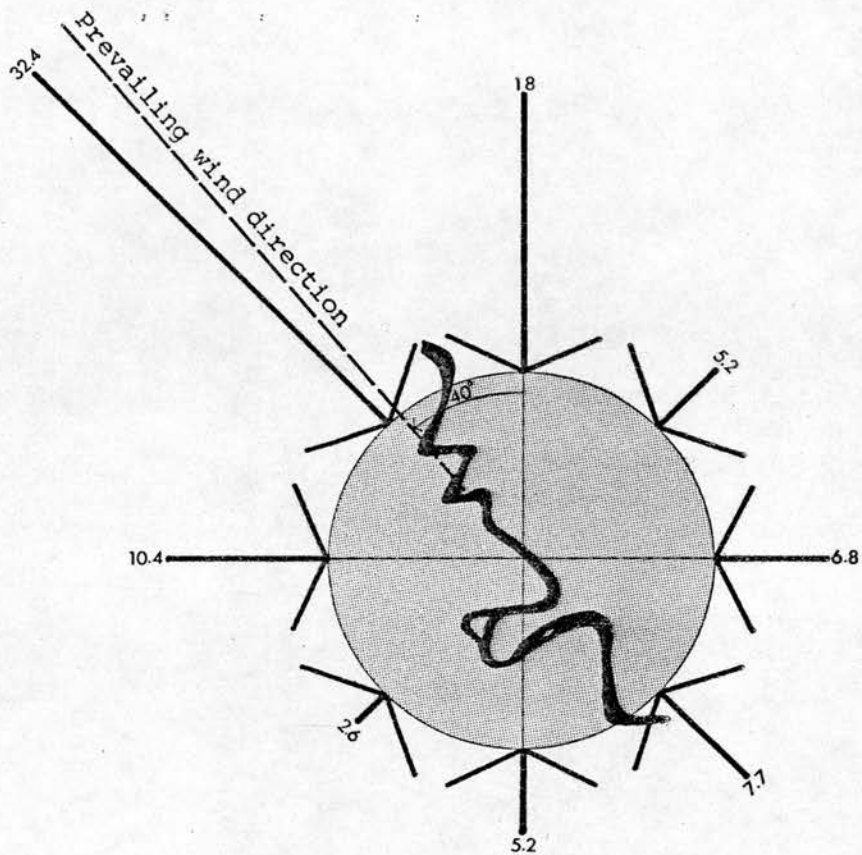


Fig.A VIII.6

Percentage of wind frequency of the eight directions and calculated prevailing wind direction.

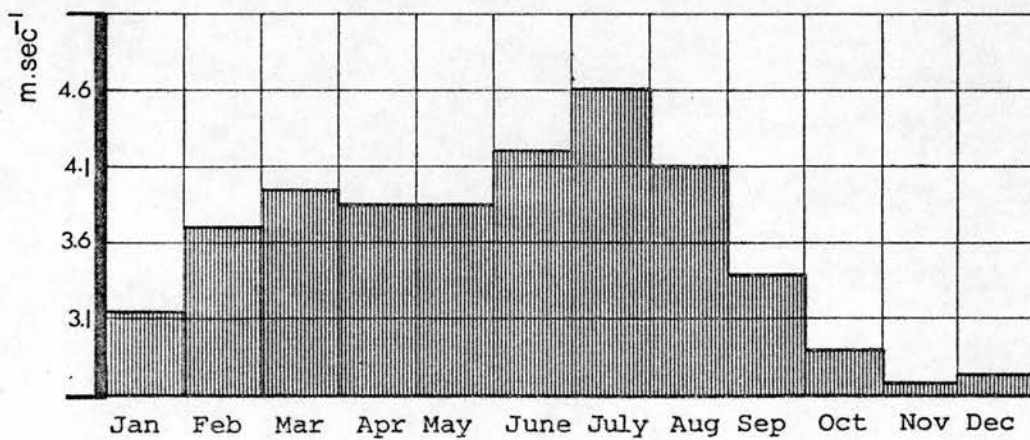


Fig.A VIII.7

Monthly mean wind speed

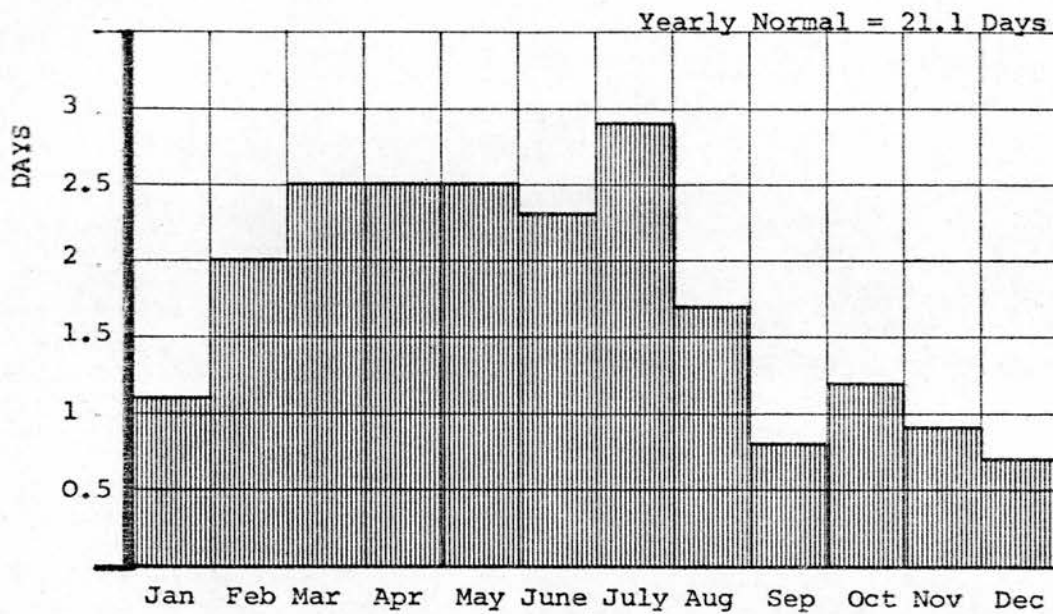


Fig. A VIII.8

Monthly normal number of days of occurrence of
Dust Storms

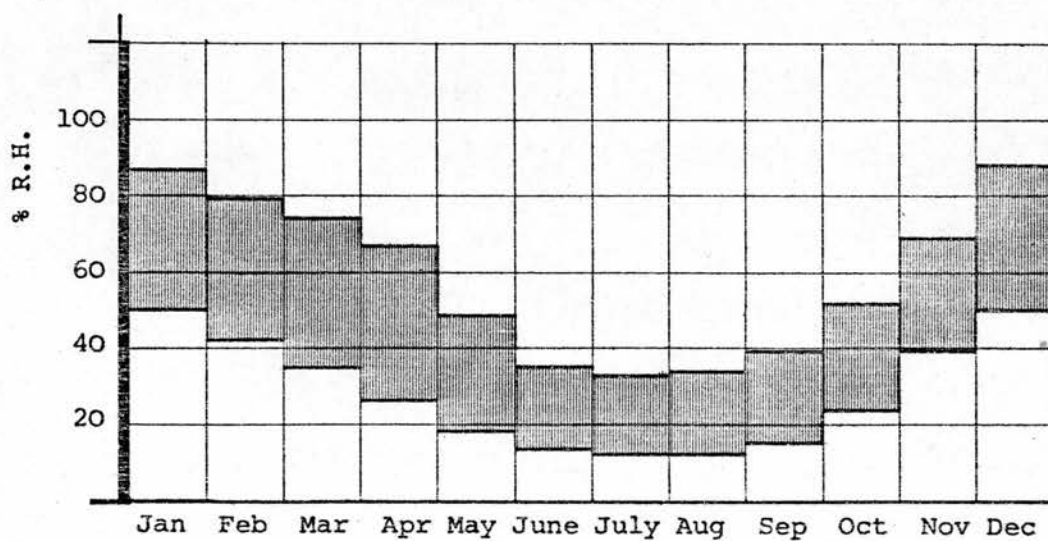


Fig. A VIII.9

Monthly mean maximum and minimum relative humidity

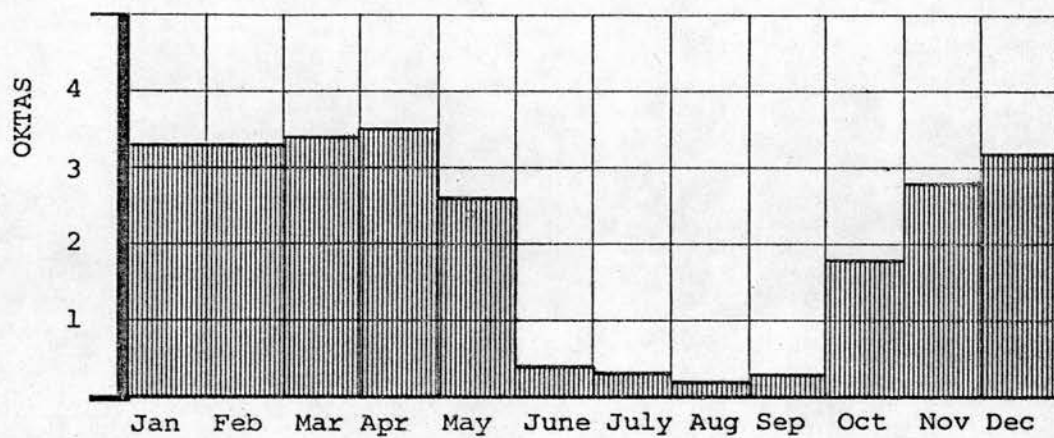


Fig. A VIII.10

Monthly Mean Daily Total Cloud

Max. Rainfall in a Day = 71mm
Yearly Mean = 146.4 mm

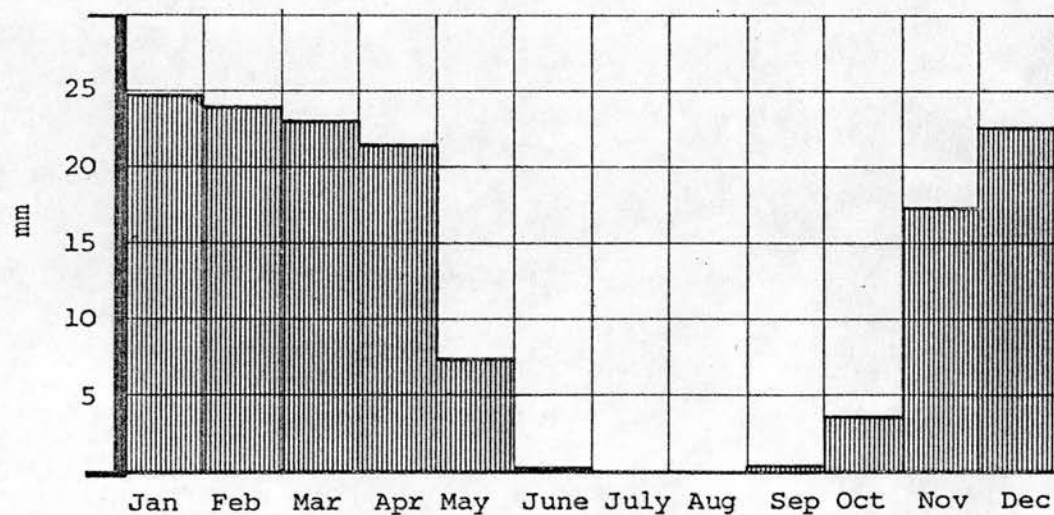


Fig. A VIII.11

Monthly Mean Daily Total Rainfall

Air Temp. (°C)	J	F	M	A	M	J	J	A	S	O	N	D
Monthly Mean Max.	16	18.5	22	29	36	41	43.5	43.5	40	34	24.5	17.5
Monthly Mean Min.	4	5.5	9	14.5	20	23.5	25	24.5	21	16	10.5	5

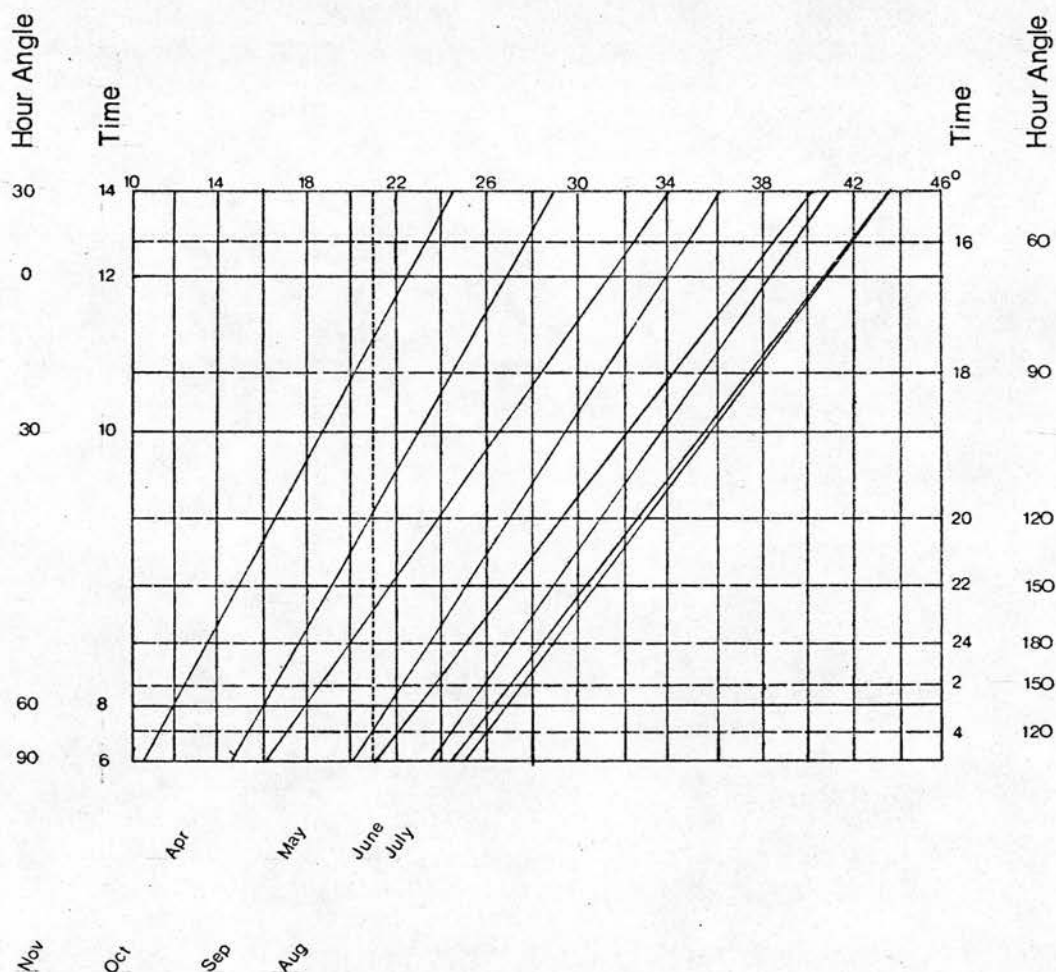


Fig.A VIII. 12

The Mahony Table and the Shading Time Chart (U.N. 1971)
with Hour Angle Indications and Baghdad Temperature Data

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